# WATERSHED AND OTHER RELATED INFLUENCES AND A WATERSHED PROTECTIVE PROGRAM

FROM

"A NATIONAL PLAN FOR AMERICAN FORESTRY"

---

A Report Prepared by the Forest Service, U. S. Department of Agriculture in Response to S. Res. 175 (72d Congress)

---

SENATE DOCUMENT No. 12 – SEPARATE No. 5

# WATERSHED AND OTHER RELATED INFLUENCES AND A WATERSHED PROTECTIVE PROGRAM

FROM

"A NATIONAL PLAN FOR AMERICAN FORESTRY"

A Report Prepared by the Forest Service, U. S. Department of Agriculture
in Response to S. Res. 175 (72d Congress)

Senate Document No. 12 - Separate No. 5

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

Copies of Senate Document 12, A National Plan for American Forestry, from which this separate has been reprinted, are on sale by the Superintendent of Documents, Washington, D.C. Price $1.75. Remittance should be made by money order.

# WATERSHED AND RELATED FOREST INFLUENCES

By E. N. MUNNS, in charge, Division of Silvics; W. R. CHAPLINE, in charge, Division of Range Research; R. D. FORBES, Director, Allegheny Forest Experiment Station; L. F. KELLOGG, Associate Silviculturist, Central States Forest Experiment Station; and H. G. MEGINNIS, Junior Forester, Southern Forest Experiment Station

CONTENTS



The forests of the United States, invaluable as a source of wood and other tangible products, have so-called "intangible" values perhaps equally great. The present section will describe the value of the forests as regulators of stream flow and preventives of erosion.

## STREAM FLOW AND EROSION PROBLEMS OF NATIONAL IMPORTANCE

Practically every section of the country is confronted by one or more serious problems of stream flow or erosion. The densely populated areas share with the areas of low rainfall the immediately vital problem of obtaining adequate and constant quantities of water for human consumption and other domestic uses. The latter areas are confronted with the additional problem of supplying water for irrigation of agricultural land. Populous industrial communities require water, often in huge quantities, for various manufacturing processes. Large sections of the country that receive light in their homes and energy in their factories from water power are concerned over low water in the streams. The threat of low water and clogged channels must also be considered by those portions of the United States where stream-borne commerce is important and navigable harbors give access to the markets of the world. Floods are often an appalling problem not only to the great fertile lowlands but also to highland valleys. And erosion—the washing of precious surface soil from land exposed to rain and melting snows—is a problem common to nearly all parts of the United States and acute in many. The magnitude of the problems of stream flow and erosion, considered in detail and region by region later in this discussion, may be judged for the Nation as a whole from the paragraphs immediately following.

### DOMESTIC AND INDUSTRIAL WATER SUPPLIES

Very heavy concentration of population and industry in certain areas, such as the North Atlantic seaboard, the Ohio River Valley, and parts of California, has created a demand for huge public water supplies. The main urban centers from Boston to Baltimore consume 2,000,000,000 gallons of water daily; in the Philadelphia district more than half of the consumption is by industrial plants. Boston plans to tap a stream 60 miles away; New York now goes 92 miles for part of its supply. The investment of New York in dams and reservoirs is $66,000,000; the adjacent communities in New Jersey plan a development to cost about $45,000,000; Baltimore is at work on a $30,000,000 project.

The great drought of 1930–31 in the northeastern United States revealed the acuteness of the domestic water-supply problem, bringing not only great actual inconvenience to rural and urban populations alike, but in the cities raising the specter of epidemics and uncontrollable fires. For example, while some farmers in western Kentucky were hauling water for livestock 20 miles, the public water supplies of several towns and cities in the Ohio Valley had to be supplemented by shipments in tank cars. Among them was Lexington, Ky., which, after drawing water by trainloads from pools in the Kentucky River for several weeks, constructed a 25-mile pipe line to the same source. The United States Weather Bureau at Cincinnati in its report on the Ohio Valley situation in October 1930, stated:

Fortunately the Federal Government had completed the dams in the Ohio River before the great drought of 1930. These dams have maintained full pools from Pittsburgh, Pa., to Cairo, Ill., during the entire summer and fall. * * * Many of the larger tributaries * * * have been improved by dams. The water from the pools in these rivers has made it possible for life to exist and business to progress in the Ohio Valley during the driest season of record.

San Francisco and the immediate vicinity will shortly obtain part of their public water supplies from the Hetch Hetchy Reservoir, 200 miles away, built at a cost of $126,500,000. In southern California half the population of the State, concentrated in an area where less than 1 percent of the water of the State is found, now obtains part of its domestic water from the Owens River, 250 miles away, and is preparing to go 200 miles to the Colorado River. Some of the deep wells from which part of the water supply for this area is obtained are being depleted or threatened with invasion by the salt waters of the Pacific Ocean, just as the deep wells of the New Jersey coast resorts are threatened by those of the Atlantic Ocean. The water system by which southern California plans to solve its water problems, primarily of domestic supplies, will cost $350,000,000.

## IRRIGATION

Irrigating water is the lifeblood of certain communities, such as southern California and the Salt River Valley in which is concentrated one fifth of the population of Arizona. It is a commodity of enormous importance to 19 States west of the Mississippi River, as is indicated in table 1. Irrigation has been the purpose for which the Federal Government has constructed a number of large reservoirs, such as Elephant Butte in New Mexico and the Arrowrock in Idaho.

Table 1.—*Acreage of irrigated land, together with value of lands, buildings, and machinery, and value of irrigation enterprises for irrigated farms, by States. 1930 Census*

| State | Irrigated area | Value of lands, buildings, and machinery | Value of reservoirs and distributing systems |
|---|---|---|---|
| | *Acres* | *Dollars* | *Dollars* |
| Arizona | 575, 590 | 157, 290, 710 | 73, 328, 197 |
| Arkansas | 151, 787 | 18, 417, 482 | 6, 836, 648 |
| California | 4, 746, 632 | 2, 535, 075, 016 | 450, 967, 979 |
| Colorado | 3, 393, 619 | 414, 180, 910 | 87, 603, 240 |
| Idaho | 2, 181, 250 | 316, 649, 034 | 84, 500, 354 |
| Kansas | 71, 290 | 13, 095, 069 | 1, 685, 652 |
| Louisiana | 450, 901 | 50, 676, 224 | 15, 744, 743 |
| Montana | 1, 594, 912 | 205, 027, 415 | 50, 319, 204 |
| Nebraska | 532, 617 | 91, 773, 733 | 21, 386, 319 |
| Nevada | 486, 648 | 63, 998, 051 | 15, 457, 931 |
| New Mexico | 527, 033 | 93, 160, 485 | 19, 834, 380 |
| North Dakota | 9, 392 | 1, 452, 335 | 1, 267, 314 |
| Oklahoma | 1, 573 | 1, 771, 383 | 160, 099 |
| Oregon | 898, 713 | 171, 919, 001 | 38, 754, 548 |
| South Dakota | 67, 107 | 11, 576, 300 | 4, 502, 117 |
| Texas | 798, 917 | 190, 141, 304 | 49, 022, 164 |
| Utah | 1, 324, 125 | 212, 258, 249 | 35, 669, 819 |
| Washington | 499, 283 | 208, 738, 027 | 40, 561, 895 |
| Wyoming | 1, 236, 155 | 129, 692, 056 | 35, 153, 187 |
| United States | 19, 547, 544 | 4, 886, 892, 784 | 1, 032, 755, 790 |

## WATER POWER

Power developed from streams has long been the backbone of the great manufacturing industries of New England and New York and of late years has made possible the industrial rise of the Carolinas. As a source of electric current for countless homes, rural and urban, and for city lighting, it is important in all but a few sections of the United States. Dams built to store water for power production rank among the Nation's great engineering feats. That at Dreher Shoals, S.C., created a reservoir with a capacity of 524 billion gallons of water. The Wilson Dam at Muscle Shoals, Ala., cost the United States $51,000,000 to build; the recently completed Conowingo Dam in Maryland cost $52,000,000 and has an installed capacity of 378,000 horsepower. Practically every State in the Union utilizes power from its streams, and the 26 States listed in table 2, scattered from Maine to California, have each developed over 100,000 horsepower.

Table 2.—*States developing more than 100,000 horsepower from stream flow*

| State | Installed capacity, 1931 | State | Installed capacity, 1931 |
|---|---|---|---|
| | *Thousand horse-power* | | *Thousand horse-power* |
| California | 2, 321 | Massachusetts | 362 |
| New York | 1, 904 | Idaho | 357 |
| North Carolina | 954 | Oregon | 354 |
| Alabama | 931 | Pennsylvania | 291 |
| Washington | 892 | Tennessee | 288 |
| South Carolina | 816 | Minnesota | 286 |
| Maine | 579 | Vermont | 202 |
| New Hampshire | 553 | Iowa | 182 |
| Wisconsin | 519 | Connecticut | 171 |
| Georgia | 482 | Utah | 157 |
| Montana | 429 | Kentucky | 145 |
| Maryland | 416 | Arizona | 137 |
| Michigan | 399 | Virginia | 135 |

## NAVIGATION

Water transport plays an important role in the distribution of goods in some parts of the United States. The inland waterways of the country, exclusive of the Great Lakes and interior and intracoastal canals, carried 130 million short tons of freight in 1929. From the founding of the Republic the improvement and maintenance of navigable channels and harbors has been a Federal responsibility. Immense sums have been spent by the War Department in the deepening and widening of natural channels, and in engineering works to make navigation possible during periods of low water. On a single stream—the Ohio River—the Army engineers built 49 locks and dams, at a total cost of some $118,000,000. The sums spent by the Federal Government on existing river and harbor projects, nearly all begun during the last 50 years, are shown in table 3 for each of the drainage regions later described in detail.

Table 3.—*Expenditures by the Federal Government on existing river and harbor projects directly connected with stream flow to June 30, 1932* [1]

| Drainage region | New work | Maintenance | Total |
|---|---|---|---|
| Northeastern | $110, 565, 800 | $41, 549, 614 | $152, 115, 414 |
| South Atlantic | 21, 925, 180 | 10, 664, 800 | 32, 589, 980 |
| East Gulf | 42, 431, 263 | 24, 890, 899 | 67, 322, 162 |
| West Gulf | 7, 840, 354 | 6, 842, 644 | 14, 682, 998 |
| St. Lawrence | 23, 536, 783 | 7, 831, 504 | 31, 368, 287 |
| Upper Mississippi | 46, 453, 997 | 17, 964, 551 | 64, 418, 548 |
| Hudson Bay | | | |
| Ohio | 273, 377, 283 | 8, 005, 056 | 281, 382, 339 |
| Missouri | 55, 694, 195 | 11, 443, 112 | 67, 137, 307 |
| Arkansas-Red | 9, 530, 642 | 5, 371, 173 | 14, 901, 815 |
| Lower Mississippi | 24, 698, 131 | 14, 933, 296 | 39, 631, 427 |
| California | 19, 694, 023 | 8, 980, 092 | 28, 674, 115 |
| Columbia | 20, 008, 737 | 8, 997, 023 | 29, 005, 760 |
| Colorado | | | |
| Great Basin | | | |
| Rio Grande | | | |
| Cascade | 12, 876, 149 | 8, 345, 876 | 21, 222, 025 |
| Total | 668, 632, 537 | 175, 819, 640 | 844, 452, 177 |

[1] Obtained from the Annual Report of the Chief of Engineers, U.S. Army, pt. I, 1932. Sums spent on harbor breakwaters, canals, and other similar improvements not connected with natural streams and hence not influenced by cover conditions have been omitted from the compilation.

## FLOODS

Floods on the lower Mississippi River of the magnitude of that of 1927, which inundated 18,000 square miles, drove 750,000 people from their homes, did some $300,000,000 worth of damage, and took 246 lives, so far overshadow disasters on lesser streams as to obscure the almost Nation-wide importance of local floods. Flood damage in South Carolina has averaged nearly $1,000,000 a year for the last 20 years, and in Tennessee has been about the same. In table 4 are given some of the major floods occurring in the present century on streams other than the Mississippi River, but the record is far from complete.

Table 4.—*Partial summary of disastrous local floods since 1900 and reported damage*

| Stream or locality | Date | Lives lost | Reported damage |
|---|---|---|---|
| | | *Number* | |
| Passaic River, N.J | 1903 | -------- | $4,000,000 |
| North Canadian River, Okla | 1932 | -------- | 1,050.000 |
| New England | 1927 | 84 | 35,000,000 |
| Paint and Armstrong Creeks, W.Va | 1932 | -------- | 2,500,000 |
| Choctawhatchee River, Fla | 1929 | -------- | 5,000,000 |
| Delaware River | 1925 | -------- | 1,800,000 |
| Brazos River, Tex | 1921 | 164 | 12,000,000 |
| Kentucky River, Ky | 1927 | 67 | 7,000,000 |
| Ohio River Valley | 1913 | 400 | 180,000,000 |
| Upper Mississippi River | 1916 | -------- | 2,500,000 |
| Wabash River, Ind., and White River, Ill | 1930 | -------- | 7,000,000 |
| Western North Carolina | 1916 | -------- | 22,000,000 |
| Pueblo, Colo | 1921 | 120 | 25,000,000 |
| Spartanburg, S.C | 1903 | 50 | 3,500,000 |
| Rio Grande, Tex | 1932 | 12 | 2,500,000 |
| Yazoo, Miss | 1932 | -------- | 1,450,000 |

## EROSION

A process common to nearly all parts of the United States is the washing by rains from unwisely cleared and unskillfully cultivated lands, from overgrazed pastures and ranges, and occasionally from devastated and badly burned forest lands of the fertile topsoil that has required centuries and sometimes vastly longer periods to accumulate. In some places the effects of this washing have reached tragic proportions. Erosion not only robs the uplands of fertility but loads the streams which drain them with silt and heavier material that clogs irrigating ditches, navigable channels, and harbors; fills reservoirs; increases the height of floods; and permanently ruins much overflowed land. Erosion is unquestionably most serious from land cleared for agriculture. So much of this land as fully justifies the careful management necessary to prevent erosion will remain in agriculture and is beyond the scope of this report. But on the piedmont plateau of the Southern States, on the rich bluff lands of the Mississippi as far north as Wisconsin, in the high valleys of the Appalachian Mountains, in the States bordering the Ohio River, in Missouri, Oklahoma, and eastern Texas, and in other agricultural sections of the United States erosion has been the chief cause for abandoning millions of acres of cleared land. All of this will continue to erode unless reclothed in permanent vegetation, such as forest or brush. Over the wide expanse of the public domain unregulated grazing has started erosion that has already seriously reduced the value of the forage and shortened the life of irrigating reservoirs.

## DOES FOREST COVER AID IN SOLVING THE PROBLEMS OF STREAM FLOW AND EROSION?

No one can question the seriousness of the stream flow and erosion problems that confront practically every section of the United States. Does the condition of the forest cover on the watersheds of streams appreciably influence stream flow and erosion, and how far may forest management be expected to aid in solving these problems?

DEFINITION OF FOREST COVER

Forest, as the term is used here and elsewhere in this report, includes both trees proper and tall brush. In the West this embraces commercial timber, woodland (pinon and juniper, for example), and chaparral—all areas except sagebrush, grassland, and other comparable prairie or desert types of vegetation. In the East it covers such degenerate forest types as scrub oak. In calculating the percentage of a drainage region which is forested, small openings within the forest have been included with the forest, but large meadows, grassland, or other non-tree-producing openings within the forest have been excluded. Windbreaks, shelter-belts, and other tree plantings carried in the census records of the Plains region as woodlots are admitted to the forest area. Cleared lands within the forest belt which have been permanently abandoned or are in process of abandonment by agriculture have been classed only as potential forest land.

Forest cover in its relation to watershed protection is considered to include: (1) The trees and tall brush; (2) the herbs and shrubs growing thereunder or in openings in the forest or brush fields; (3) the litter, or fallen leaves, branches, down trees, and other vegetative material on the forest floor; and (4) the rich humus of partly decayed vegetable matter at the surface and in the top layer of the soil. Thus in this section it is the influence of the entire forest cover upon run-off, erosion, or other watershed-protection values which is given consideration, rather than the influence of the trees alone.

There is a rather widespread popular acceptance in this country of the idea that forests and associated or related vegetation exert a favorable influence not only on streams but on climate. This probably had its origin in European experience, and has been fortified by general observation, such as the muddiness of streams flowing from cleared land compared with the clarity of those flowing from woodland, and extreme fluctuations in the rate of streamflow from deforested or denuded land. Only of late has a body of information based on careful observation and experimentation begun to accumulate behind the popular concept of the forest as a regulator of stream flow and preventive of erosion.

This concept of the beneficial influence of forests has been embodied from the first in the administration of the national forests created from the public domain, and was long the sole basis for purchase of national forests in the East. The act of 1897, which first provided for administration of the original "forest reserves", named as a major purpose "securing favorable conditions of water flows". Certain of the national forests of the West—among them the Tonto in Arizona and the Angeles in California—have been created in whole or in large part principally for the protection of irrigation projects or municipal water supplies. The Weeks Law of 1911 provided for Federal cooperation with the States "for the protection of the watersheds of navigable streams", and for Federal "acquisition of lands for the purpose of conserving the navigability of navigable rivers." The Clarke-McNary Law of 1924 continued the cooperation "with a view to the protection of forest and water resources", and directed that in further purchases "due consideration" be given both to watersheds of navigable streams and those "from which water is secured for domestic use or irrigation." Nearly 60 percent of the Federal pur-

chases of forest land made since 1924 have been made primarily for watershed protection.

In direct opposition to the popular idea regarding beneficial forest influences have been the doubts from time to time implied or expressed by various small groups of engineers, geologists, and meteorologists. The Mississippi River Commission, for example in its 1927 plans for controlling floods in that stream, set up grounds "to justify rejection of reforesting as an element of flood control in the lower Mississippi River", and has ignored the possibility that proper management of the 20 percent of the watershed still in forest may reduce flood crests by the critical feet or inches that often spell the difference between mere high water and disaster. Other men of scientific standing from time to time attempt to prove that because forests and similar vegetation are well known to appropriate to their use considerable quantities of ground water, particularly at seasons when streams are low, their influence is detrimental rather than beneficial. In the face of criticism of this character it is desirable to summarize here the more important available experimental evidence on the relation of forests to stream flow under American conditions of climate, soil, and vegetation.

## HOW FOREST COVER INFLUENCES RUN-OFF

The average yearly rainfall (including snow) in the United States varies from less than 10 inches in the more arid portions of the Southwest to more than 100 inches in the Pacific northwest and in portions of the southern Appalachian Mountains. In some parts of the country the rainfall is concentrated within a few months, or in a few heavy storms, while in others it is so well distributed that the precipitation for the wettest month is rarely more than twice that for the driest month. These figures are averages for a period of years; irregularities—both excesses and deficiencies in rainfall, often of extraordinary magnitude—are common to practically all sections of the country, although particularly marked in a few.

Whether the rain and snow falling on any watershed is as fully useful to mankind as it might be depends almost wholly on the character of its run-off. Of that which sinks into the ground—that is, is absorbed by the surface soil or percolates through it to greater depths—the greater part becomes available for the growth of plants useful to man or his domestic animals, or in time appears in streams capable of furnishing fairly constant supplies of water for domestic, industrial, and irrigating use, of generating water power, and of transporting freight. Or it may be stored in natural underground reservoirs available to human use. The precipitation which quickly reaches the streams by flowing over the surface of the ground, on the other hand, causes much erosion and many floods. This general classification of subsurface run-off as useful, and flashy surface run-off as detrimental, is of course subject to many exceptions. Not all vegetation using rain that has penetrated the ground is directly useful to us, and some of this water is lost through chemical combination in the soil and through seepage to great depths. Even subsurface waters when they reach the streams may contribute to floods, and the flashy run-off under some conditions may be stored above or below ground, and thus be prevented from causing destructive floods or being lost to human use during dry seasons. These instances are, however, so

exceptional and the beneficial effects for which they are responsible are so slight in comparison with the damage ordinarily wrought by run-off that they may be dismissed here as entirely negligible.

Studies of surface run-off from forested areas, and from areas in other types of natural or planted vegetation have been made in Wisconsin and in Mississippi. On silt loam uplands in Wisconsin [1] with slopes averaging 36 percent, the proportion of total summer precipitation which ran off over the surface of the ground beneath hardwood forests of varying density averaged 2.8 percent. Wild pastures of native grasses, in which the soil had never been cultivated, showed a surface run-off about 2½ times as great. Cultivation greatly increased the percentage of surface run-off; from cultivated hay fields it averaged 17.7 percent, and from small grain fields, cornfields, seeded pastures, and fallow land it averaged over 25 percent.

H. G. Meginnis of the Southern Forest Experiment Station made a study of run-off and erosion from the upland loess soil of northern Mississippi by means of a number of sample plots. At the time of the disastrous flood in the Yazoo River in 1931–32 when 27 inches of rain fell, 62 percent of the rain ran off immediately from the plots located in cultivated fields, and 54 percent from those located in abandoned fields. The run-off during the same period from the plots in an undisturbed oak forest was only 0.5 percent and but 2 percent in a scrub oak forest.

Total run-off can of course be measured only at the foot of slopes, or wherever the precipitation which has percolated into the ground is again brought to the surface by the outcropping of bedrock or impervious soil layers, and joins that which has run off over the surface. The volume of streams, compared with the precipitation received by the watershed above the point where stream volume is measured, indicates total run-off only so far as there is no deeper movement of moisture in the soil beneath the stream channel. In the drier portions of the United States stream flow for an entire year may be as little as 6 percent of the total precipitation on a watershed,[2] although averaging more, but in the more humid portions is almost always higher. In the Middle West—Missouri and Illinois, for example—the total run-off as measured by surface flow averages 20 to 30 percent [3] with minima of probably 15 percent. In the East the average total run-off in streams is more nearly 50 per cent of the precipitation and rarely drops below 25 percent. King [4] gives the average percentage run-off for Tennessee rivers as 45 percent with extremes of 12 and 66 percent.

The principal factors which influence the normal division of run-off into useful subsurface waters and less useful or destructive surface waters are the character of the precipitation, the geology and topography of the surface on which it falls, and the vegetative cover on that surface. The vegetative cover is the only one of these factors which it is within human power to control. Hence the necessity for understanding how it operates. Forest is the cover on by far the greater part of the United States which is still in natural vegetation, and on which important quantities of rain or snow fall. The more

[1] Bates, C. G., and Zeasman, O. R. "Soil erosion." Wisc. Agr. Exp. Sta. Research Bul. No. 99, 1930.
[2] Blaney, H. F. "Discussion of 'forests and streamflow'." Proc. Amer. Soc. Civil Eng., Dec. 1932.
[3] Duley, F. F., and Miller, M. F. "Erosion and surface run-off under different soil conditions." Mo. Agr. Exp. Sta. Research Bul. No. 63, 1923.
[4] King, W. R. "Surface waters of Tennessee." Div. of Geol. Dept. of Educ. Bul. 40, 1931.

important ways in which they bring about their total effect on run-off are explained in the following paragraphs.

### INTERCEPTION OF PRECIPITATION

Anyone who has taken refuge under a tree during a summer shower knows that the crown of both evergreen and broadleaf trees intercepts and holds a certain amount of the rain, which is later evaporated, but that if the rain is prolonged until the leaves and branches are thoroughly wet, the remainder of the fall reaching the tree drips and is not caught but only delayed in reaching the ground.

The Forest Service has recorded rainfall at paired stations inside and outside of timber stands in several forest types. Records of 3 to 5 summers show that a good pulpwood stand of spruce, fir, and some paper birch in Maine intercepted 26 percent of the rainfall; another Maine stand of pure spruce-fir, 37 percent; a dense saw-timber stand of white pine and helmock in Massachusetts, 24 percent; and a heavy virgin white pine and hemlock stand in Idaho, 21 percent. Briefer studies record that open second-growth forests of oak and hard pine in southern New Jersey intercepted 13 percent of the summer's rainfall; and jack pine and hardwood-hemlock stands in Wisconsin, 22 and 19 percent, respectively, of the spring and fall precipitation. The Wisconsin hardwoods when in leaf intercepted 25 percent, as against 16 percent after the leaves fell.

Interception of snow by the crowns of ponderosa pines at about 4,500 feet elevation, in Idaho, was studied by the Forest Service during 1931–32. In a good stand of virgin timber with an understory of young trees, C. A. Connaughton found that up to the time of maximum storage 27 percent of the winter's snow had been intercepted; in similar mature timber without an understory it was 22 percent; and in a somewhat open stand of ponderosa and lodgepole pine, 20 to 30 feet tall, 8 percent. Studies by Church,[5] Jaenicke and Foerster,[6] and Griffin,[7] however, indicate that snow interception is considerably less in evergreen forest types elsewhere in the West.

### RETARDATION OF SNOW MELT

Although MacKinney [8] found that light snows melted more rapidly on litter than on mineral soil under a pine plantation in Connecticut, in regions of heavy snow a forest cover retards melt in the spring, thereby materially lessening destructive surface run-off and promoting percolation of the melted snow into the ground. This is due in part to shading of the ground, but mostly to reduction in wind movement; Connaughton found the wind movement during the period of rapid snow melt in Idaho to be more than nine times as great in the open as in the heavy stand of mature ponderosa pine with an almost continuous understory of advance reproduction. Even in the open ponderosa pine forest in which Jaenicke and Foerster worked the wind movement was less than half that in the open.

---

[5] Church, J. E. Jr. "The conservation of snow. Its dependence on forests and mountains." Scientific American Supplement, Sept. 7, 1912.

[6] Jaenicke, A. J., and Foerster, M. H. "The influence of western yellow pine forest on the accumulation and melting of snow." Mo. Weather Rev., Mar., 1915.

[7] Griffin, A. A. "Influence of forests upon the melting of snow in the Cascade Range." Mo. Weather Rev., July, 1918.

[8] MacKinney, A. L. "Effects of forest litter on soil temperature and soil freezing in autumn and winter." Ecology, July, 1929.

The following information on retardation of snow melt was obtained in the snow studies just cited. In Idaho the snow cover disappeared in the forest from 3 to 10 days later than in the open; at least 10 days later in Nevada; "several weeks" later in Arizona, the snow occurring, however, merely as drifts in the timber; and from 1 to 5 weeks later in Washington. Ashe [9] reported that 20 inches of snow falling at an elevation of 600 feet in Maryland during March 1906 was 9 days longer in melting beneath a cover of Virginia pine than in the open, and also longer though by a smaller interval beneath an oak forest than in the open.

### REDUCTION OF EVAPORATION FROM THE SOIL

In addition to intercepting precipitation and retarding snow melt, the crowns and trunks of trees greatly reduce the rate of evaporation from the soil, just as they have been seen to lessen evaporation or sublimation of snow. In regions of low rainfall, where the forest is open and litter is not continuous or deep on the forest floor, reduction in evaporation from the soil is very much to be desired. W. C. Lowdermilk found, in an analysis of factors affecting the yield of water from watersheds in southern California, in 1930, that if all rain in southern California were to occur as 0.5 inch storms one week apart evaporation would account for practically the total supply of meteoric waters. Although half an inch of rain may penetrate the soils of this region to a depth of about 8 inches, when the surface is dried by sunlight and wind, the moisture is drawn up by capillary action and is evaporated. Burr [10] also found on cultivated ground in Nebraska that a half-inch rain was of no storage value unless it fell on a surface still moist.

Fortunately, all the rain does not occur in California, Nebraska, or anywhere else in the United States in small storms at weekly intervals, and evaporation from the soil is universally influenced by a forest cover which not only shades the ground but greatly reduces wind movement. In Arizona, according to Pearson,[11] summer evaporation a few feet above the ground within a forest of ponderosa pine may be only 70 percent of the evaporation in the open. G. M. Jamison found that during July and August 1931, evaporation beneath a dense virgin forest of western white pine and hemlock in Idaho was only 22 percent of that in an area clear-cut and burned, and in a similar stand from which about 65 percent of the cover had been removed it was only 47 percent. Bode [12] states that in a heavy oak stand in Iowa summer evaporation was 47 percent, and in a reproducing cut-over area 74 percent of that in the open. O. M. Wood found that evaporation during one spring in a rather open, short-bodied stand of mature pine and oak in southern New Jersey was only 65 percent of that in the open.

It is impossible to state what effect these very substantial reductions in evaporation rate within the forest have upon soil moisture. There are almost no American data on seasonal evaporation from a bare soil,

---

[9] Ashe, W. W. "Relation of soils and forest cover to quality and quantity of surface water in the Potomac basin." U. S. Geol. Sur. Water Supply Paper No. 192. 1907.

[10] Burr, W. W. "The storage and use of soil moisture." Nebraska Agri. Exp. Sta. Research Bul. no. 5. 1914.

[11] Pearson, G. A. "Forest types in the Southwest as determined by climate and soil." U.S.D.A. Tech. Bul. no. 247. 1931.

[12] Bode, I. T. "Relation of the smaller forests area in nonforested regions to evaporation and movement of soil water." Proc. Iowa Acad. Sciences. 1920.

and they would not apply to the normally litter-covered soil of a forest. European evidence, as quoted by Zon,[13] shows wide variations, but indicate that evaporation from bare soil in the open, under average conditions, amounts to about 50 percent of precipitation; and that a forest, even without leaf litter, may reduce this to 15 to 25 percent.

### CONSUMPTION OF WATER BY FOREST VEGETATION

The water which all plants rooted in the soil withdraw from it in maintaining growth and life is transpired, or given out into the air, chiefly from the leaves. It is very difficult to measure accurately the transpiration from a single tree beyond the seedling stage, and infinitely more so to measure the transpiration from a forest. Blaney *et al.*[14] employed observations of stream flow to determine the water evaporated from the soil or consumed by canyon-bottom vegetation—"willows, tules, and kindred moist land growths"—in southern California.

The evapo-transpiration losses from Temescal Canyon during only 30 spring days they found to equal 12.9 inches of rainfall. The same author[15] estimated from stream-flow measurements in Coldwater Canyon that the transpiration losses from "alders, sycamores, bay, oak, and herbaceous growth" during the 6-month summer season of 1931 was 45 inches per acre. Evaporation was judged to be small as the water in the canyon bed is constantly cooler than the air. Inasmuch as the precipitation for the entire year is normally only about 30 inches, it is fortunate that the area of canyon-bottom vegetation is very small, and that the loss per acre of entire watershed is only 0.10 inch per mile of canyon. The transpiration losses just described are probably at or near the maximum for any forest type in the United States, and fully warrant the expedient, already adopted by such cities as San Bernardino, of piping water out of the stream channel before it can be consumed by the canyon-bottom forest. That the forest cover of the slopes and ridges in this region does not begin to make the same demands on soil moisture is very clear from its dwarfed development.

Data on transpiration rates for other American forest types are entirely lacking and these rates may only be inferred from general knowledge. Interception of precipitation, evaporation from the soil, and transpiration account for a very large part of the difference between the total precipitation over a watershed and the flow of the stream draining it. These differences have been earlier described for various parts of the country. Transpiration probably fully equals the other two factors combined in the hardwood forests of the humid eastern United States, but in the evergreen and chaparral forests East or West, may be subordinate to either.

### INFLUENCE OF FOREST LITTER

Probably more important than any of the previously listed influences of the forest on run-off and stream flow is that exerted by litter.

---

[13] Zon, R. "Forests and water in the light of scientific investigation." Final report, Nat. Waterways Com., Sen. Doc. no. 469, 62d Cong., 2d sess., 1912.

[14] Blaney, H. F., Taylor, C. A., and Young, A. A. "Rainfall penetration and consumptive use of water in the Santa Ana River valley and coastal plain." Calif. State Bul. no. 33. (Calif. Dept. Public Works, Div. Water Resources, in coop. U.S.Dept. Agr., Bu. Agri. Engineering) 1930.

[15] Blaney, H. F., Discussion of "Forests and Stream Flow." Proc. American Soc. of Civil Eng., December 1932.

Forest litter is the layer of fallen leaves or needles, of dead branches, down trunks, and other vegetable remains, which in varying depth is found under the crowns of trees and brush species in every temperate-zone forest. Through the gradual processes of decay and chemical change, and through the agency of animals which trample or otherwise disturb the surface of the ground, this litter is disintegrated into humus. Percolating water then carries the fine particles of humus, into the soil, where they are further broken down into nitrogenous products by bacteria and other organisms.

Forest litter exerts its influence in several ways. First and most important, it contributes to the humus content of the soil. It is an axiom in agriculture that humus, or organic matter, makes a heavy soil lighter, and a light soil heavier, by causing the soil particles to form crumbs. A crumb structure gives the maximum room for air and water, both vital to plant growth. How powerful an effect organic matter, although an unimportant fraction by weight in most soils, has on the water-holding capacity of the soil is illustrated by analysis in table 5, made by George Stewart of a granitic sand supporting ponderosa pine in Idaho. About 200 samples of the soil were taken to a depth of 4 inches, from openings, some large and some small, in a virgin stand. The condition of the vegetation refers to its value primarily as forage, and the deterioration is the result of grazing.

TABLE 5.—*Analysis of granitic sand soil under a ponderosa pine stand in Idaho*

| Condition of vegetation | Organic matter[1] | Water-holding capacity[1] |
|---|---|---|
| | *Percent* | *Percent* |
| Good (nearly original condition) | 10.5 | 81 |
| Intermediate (considerable deterioration) | 4.8 | 55 |
| Poor (bad deterioration, soil usually gullied) | 2.4 | 44 |

[1] In percentage of dry weight of soil.

The ability of this soil to absorb water was nearly halved by its loss of a very small quantity of organic matter. Inasmuch as the soil of any watershed is the great underground reservoir replenished from time to time by precipitation, but at all times draining into the streams, its absorptive capacity is the great factor in sustained streamflow. Humus and the decaying roots of plants enormously increase this capacity.

A second major influence of forest litter is its promotion of water percolation. If a soil is extremely shallow, or if precipitation is unable to percolate into it rapidly, run-off must take place over the surface from any but the lightest storms. If rain falls upon bare soil it becomes muddied and carries fine material in suspension downward into the minute interstices between the soil particles. How promptly and completely muddy water will plug these pores and slow the rate of percolation has been demonstrated by Lowdermilk.[16] After establishing, over a period consisting of parts of 7

[16] Lowdermilk, W. C., "Influence of forest litter on run-off, percolation, and erosion." Jour. Forestry, April 1930.

days, the rate at which clear water percolated through columns of soil, he introduced sediment of less than 2 percent by weight into the water; within 6 hours the rate of percolation fell to 10 percent of what it had been. Moreover, the effect was permanent, as a return to the use of clear water did not restore the original rate. A good forest litter keeps the rain from becoming muddied when it hits the earth and so decreases run-off; in the absence of litter, surface run-off is enormously increased. When Lowdermilk applied artificial rain, at an average rate of 1 inch an hour, for several periods of ½ to 8 hours, to sloping tanks filled with typical California soils, he found that the surface run-off was from 3 to 16 times as great from bare soils from which the litter was burned as from those on which a litter cover was present.

An effect similar to that of litter cover in aiding percolation and in lessening the proportion of surface run-off is produced by low, permanent vegetation. Duley and Miller (op. cit.) state that whereas only 11.5 percent of 6 years' rainfall ran off over a sloping surface protected by a permanent grass sod, kept clipped, 49 percent ran off bare soil. Even where tilth of the bare soil was maintained by annual cultivation nearly 30 percent of the precipitation was carried off over the surface.

The superior physical condition and consequent permeability of forest soils has been demonstrated for Ohio Valley conditions by Auten.[17] Samples of the upper 9 inches of soil under several old-growth stands in oak-hickory and other hardwood types were found to be 13 percent lighter at oven dryness than equal volumes of soil from adjacent cultivated fields and a few pastures—indicating more pore space and better tilth. Although this difference in weight was later found to be confined to the upper 6 inches, the forest soil was still distinctly the more pervious to moisture at a depth of 8 inches. At a 3-inch depth 14 times as much water was absorbed per minute by the forest as the field soil, and at a 1-inch depth, over 50 times as much.

Auten points out that the favorable effect of the forest on the soils he studied is not entirely due to the litter, but is increased by the roots, which upon their death decay and leave the soil interpenetrated with tube-like cavities; also by the activities of burrowing worms, insects, and animals, which make the soil porous. A litter cover promotes these activities. Lowdermilk reported that earthworms appeared under the litter during the second year of his comparison of run-off from bare and litter-covered plots.

Secondary but sometimes important effects of litter upon run-off are produced by its absorption of moisture, its retardation of evaporation from the soil beneath, and its prevention of deep freezing. Investigations by the Forest Service and other agencies[18] have shown that litter from both the conifer and oak-chaparral types of California absorb about 1.8 times their own dry weight of moisture; freshly fallen pine litter in both the Lake States and the South, 1.5 times; conifer litter in the southern Appalachian Mountains, 3.4 times and hardwood litter, 4.6 times; and spruce-northern hardwood litter in New England up to 9 times its dry weight. The rainfall

[17] Auten, John T., "Porosity and water absorption of forest soils." Accepted for publication by Jour. Agr. Res., 1933.

[18] "Relation of forestry to the control of floods in the Mississippi Valley." House of Rep. Doc. No. 573, 70th Cong., 2d sess., 1929.

equivalent of moisture absorbed by the litter normally accumulating in this wide assortment of types ranges from a negligible quantity to nearly an inch, and within a single region, according to Alway and Harmer,[19] may be 9 times as much in a dense stand as in one opened by cutting. The Red Plains Experiment Station near Guthrie, Okla., found the litter on a post-oak area to have a water-absorption capacity of 16.7 tons per acre.

American data on the effect of a litter cover on evaporation from forest soils are singularly lacking, but European comparisons, quoted by Zon (op. cit.) of forests with and without litter, indicates that this natural forest mulch may reduce evaporation by 40 to 60 percent.

A litter cover materially retards both the rate and depth of freezing of the soil beneath. MacKinney (op. cit.) found that under a 2-inch litter in a Connecticut plantation of Norway and white pines, frost in 1926–27 was a month later in penetrating the soil at all, and final penetration only 60 percent as deep, as where the litter had been removed.

> The character of the frozen soil was influenced markedly by the litter. The soil on the bare plot froze solidly, and the air spaces were practically filled with ice. On the other hand the frozen soil beneath the litter cover was porous and loose, at no time being frozen too hard to allow the insertion of a shovel * * *. During winter rains and thaws, the water soaked into the soil of the litter-covered plot and percolated to lower depths. On the bare plot the water ran off at such times due to the nonporous character of the frozen soil.

## SUMMARY OF INFLUENCES

Because forest that conserves snow and reduces evaporation of soil moisture must at the same time interrupt precipitation and transpire water drawn from the soil, its final effect on run-off can only be determined by the balance between these opposing influences. Whether this net effect is beneficial or harmful in any particular region is probably determined in part by the total amount of precipitation, but chiefly by the occurrence of precipitation as snow or rain, its distribution throughout the year or during only a part of it, and its arrival in light or heavy storms. American research to date, backed by a large body of observational evidence from all parts of the United States, justifies a strong belief that the forests of the country practically always benefit stream flow. A possible exception is the canyon-bottom vegetation of the drier regions, earlier described; even this may prove to have a net favorable effect in the checking of erosion. There can be no doubt at all that the net effect of forest litter, although it intercepts some precipitation and returns it into the air by evaporation, is extremely beneficial, since it reduces surface run-off and increases the water-storage capacity of the soil by increasing percolation at the same time that it shelters the soil moisture from evaporation.

From a careful consideration of each main region, it appears fairly evident that the climax forest—that type of forest which is best adapted to the climate and soil, and which nature, in the absence of fires, human interference, or epidemic of tree-killing insects and diseases, always tends to produce—was admirably adapted to promoting stream-flow conditions favorable to mankind. For example, the dense hardwood and hemlock forests of the southern Appalachian Moun-

[19] Alway, F. J., and Harmer, P. M., "Minnesota glacial soil studies: II. The forest floor on the Late Wisconsin Drift." Soil Science, 1927.

tains, where annual rainfall is heavy and floods result from a succession of storms rather than from a single very heavy storm, appear to constitute just the forest type to intercept the maximum of precipitation in the tree crowns and litter, and to reduce the flood crests by keeping part of the rain or melted snow from ever reaching the soil. Were such a forest capable of developing in southern California, where the comparatively light precipitation supplies a vital human need in the rich valleys, its draft on available moisture would be extremely serious. But the forest actually present on the hillsides is a dwarfed one, not transpiring appreciably at the season of heaviest rainfall, but producing a leaf litter having a profoundly favorable effect on percolation and water storage.

The natural climax forest of a region, although a valuable guide to what constitutes the best form and composition for a forest managed chiefly for its influence on run-off and stream flow, is probably not beyond improvement. When vastly greater research than has yet been attempted yields a knowledge of how much a given change in the character of a forest will improve the flow of streams, it is entirely possible that appropriate management will produce a forest with an even greater beneficial influence than the original. At the very least man has it somewhat in his power to control many of the natural catastrophes—fire and killing insects, for example—that ravaged some of the American forests long before Columbus' arrival, and which, as will be seen under a later heading, today have disastrous effects on stream flow.

## HOW FOREST COVER INFLUENCES EROSION

Erosion, the removal of soil by water and wind, is taking place on all land areas. Where this occurs on land that has not been disturbed by man and is subject to no extraordinary climatic conditions the process may be termed "normal erosion." The intensity of normal erosion is determined chiefly by topography, geology, soils, climate (especially precipitation), and vegetative cover. Only rarely does it assume an intensity that involves serious damage to soil or to water flow or storage. In humid regions completely clothed with vegetation, as in a dense forest, natural processes are forming soil as rapidly as it is eroded and actual net loss, if any, is imperceptible. Surface run-off is ordinarily negligible, and consequently what erosion there may be is limited to light or dissolved particles of organic matter and practically no mineral soil is removed. Where the forest and other vegetative cover is definitely scant, as under semiarid conditions, there is still enough vegetation or debris to catch eroding soil and litter on slopes, retard run-off, and cause deposition of much of the eroded material already in motion. Even a light vegetative covering, if undisturbed, is sufficient to hold normal erosion to a negligible quantity. Only where the soil is unstable and easily erosible, as in the Badlands of the Dakotas, or on the outcrop of the Mancos and other similar shales, is normal erosion sufficiently rapid as to be perceptible.

On the other hand, when natural conditions are disturbed and nature's balance is upset by a reduction in the forest cover as a result of fire, logging, or overgrazing, or by marked changes in climatic conditions or other major causes, erosion in excess of normal is liable to occur. Furthermore, abnormal erosion, where it does occur, is an

accelerating process. Its least conspicuous form is as sheet erosion, recognizable in the exposure of root crowns and roots of plants, in the lowered productivity of the site, in the accumulation of soil on slopes immediately above obstructions, and in the final disappearance of the mellow black surface soil. As the mellow surface soil is washed away, a more compact subsurface soil is generally exposed, less capable of absorbing rainfall and less resistant to erosion. Furthermore, decreased productivity may render it incapable of supporting as dense a stand of vegetation as formerly. There is thus less obstruction to run-off, less binding power in the soil, and less possibility of rebuilding the organic content. As sheet erosion becomes advanced the more rapid surface run-off concentrates and tends to cut small gullies. After hard rains on soils inadequately protected by vegetation the entire area may be cut by lines from the size of a pencil to gullies several inches deep. The smaller lines may be readily obliterated by creep of soil as it dries, but their original presence indicates a rapid soil wastage.

Finally, abnormal erosion assumes its most spectacular form as deep gullies on slopes and large straight-sided channels cut through flood plains. Its final effects are heavily soil-laden streams, especially when in flood; silted channels and reservoirs; mud rock flows from mountain stream courses; and deposits of inert sands and gravels on fertile bottom lands.

The control of erosion through retarding run-off is largely a function of the forest cover. This cover is responsible for improvement of soil structure, protection of the surface soil from beating rains, and, by intercepting run-off, reduction of the velocity and carrying power of the surface water. Lowdermilk has pointed out in his studies under controlled conditions that the run-off from soil surfaces protected by a litter cover alone was nearly clear. A summary of Lowdermilk's findings in table 6 shows strikingly the value of forest litter in reducing erosion on three important soil types. The weights of soil eroded from these plots, all of which had been litter covered for a year before half of them were burned bare, indicate that, on the average, removing the litter caused, respectively, 73, 160, and 1,196 times as much sediment to be eroded as was carried off from the protected soils. Studies in Arizona by C. K. Cooperrider, of the Southwestern Forest and Range Experiment Station, show that a vigorous herbaceous and shrub understory in the woodland type exerts a somewhat similar influence.

TABLE 6.—*Weights of soil eroded from plots protected by litter cover and plots burned bare on slopes of equal gradient and soils of three important types, under equal quantity and duration of artificial rainfall* [1]

| Time of run (hours) | Average total rainfall | Sandy clay loam | | Fine sandy loam | | Clay loam | |
|---|---|---|---|---|---|---|---|
| | | Litter covered | Bare | Litter covered | Bare | Litter covered | Bare |
| | *Inches* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* |
| ½ | 7.86 | 0.05 | 18.6 | 2.00 | 234.0 | 0.51 | 285.4 |
| 1 | 15.44 | .40 | 40.6 | 1.70 | 646.8 | .60 | 593.7 |
| 1½ | 21.45 | 2.00 | 38.2 | .95 | 28.1 | .44 | 1,279.4 |
| 2 | 20.17 | .35 | 89.6 | .59 | 235.6 | 2.02 | 1,238.2 |
| 4 | 43.19 | .45 | 35.4 | 2.48 | 19.0 | .75 | 404.1 |
| 8 | 77.31 | .50 | 48.6 | 1.07 | 235.6 | .62 | 2,082.2 |
| Average | ---------- | .62 | 45.2 | 1.46 | 233.2 | .82 | 980.5 |

[1] 10 runs made for each combination of time and condition.

Water erosion, however, is not the only form of erosion. Wind erosion, resulting in the formation of sand dunes, occurs in areas where trees or other vegetation are not able to hold light soils from transportation by high winds. Destructive dunes exist west of the Adirondack Mountains in New York, along the eastern shore of Lake Michigan and other Great Lakes, and in places along the Pacific, Atlantic, and Gulf coasts. Forests offer a possibility for the control of sand dunes in localities where climatic conditions are sufficiently humid to permit the establishment of a forest cover. In Europe many dune areas have been transformed by planting to good timber-producing forests, some of which served admirably for wood products in the World War. The establishment of trees or similar vegetation on dune areas breaks the force of the wind, and the litter cover, once complete, protects the soil from wind transportation.

## CONSEQUENCES OF DISTURBING THE FOREST COVER

### FIRE

Fire is the most wide-spread and one of the most destructive disturbances of the forest cover. Even the lightest fire consumes some of the inflammable materials on the ground—the litter in all its forms. The extent of destruction of these materials depends in the main upon their moisture content, and the humidity and other climatic factors at the time of the fire. In many forest types it is a common occurrence for the litter to be entirely consumed by a fire which does not do any spectacular damage to the standing trees. Thus is destroyed the enormously important protective soil covering, a chief factor in the forest's favorable influence on run-off and erosion. A fire which is hot enough to consume most of the litter ordinarily also destroys part of the humus in the top soil, thus damaging its loose, porous, granular structure, and making it less receptive to penetration of rain.

Bennett [20] in reporting on an unpublished finding of S. W. Phillips and I. T. Goddard at the Red Plains Erosion Experiment Station near Guthrie, Okla., in the spring of 1930, states that on two plots in post-oak timber—one on which the forest litter was burned, and the other, immediately alongside, on which the natural ground cover of leaves and twigs was left undisturbed—the run-off was measured during a period of almost continuous rainfall in May. Run-off from the unburned plot was clear and amounted to 250 gallons per acre, but that from the burned plot, having the same soil and slope, was muddy and attained a volume of 27,600 gallons per acre. The excess of run-off from the burned area over that from the unburned area plus the 16.7 tons per acre absorbed by the leaf-litter itself was approximately 90 tons per acre. The absorbed water went to replenish the underground soil water supply while that held by the litter was largely evaporated. From the burned plot an average of 0.15 ton of soil per acre per year was eroded, and from the unburned plot 0.01 ton.

In spruce forests of the East, particularly at high altitudes, fires have been very destructive. Here the mineral soil is shallow, and in

[20] Bennett, H. H., Relation of Erosion to Vegetative Changes, pp. 385–415. Scientific Monthly, November 1932.

places almost lacking, under a deep duff. Where this covering has been burned, the soil itself is practically destroyed. Studies by the Appalachian Forest Experiment Station on a 1924 burn in West Virginia indicated that spruce and hardwood litter from 12 to 18 inches deep was destroyed. In his report on the southern Appalachian region, which had a large influence in bringing about the purchase of national forests in the eastern United States region, Glenn [21] said of the Blackwater Basin in Virginia:

> All of the Blackwater Basin except its lower part has been thoroughly lumbered and then burned over, so that in many places the bare rocks are exposed and scarcely anything but briers and fire-scald cherries have since been able to take hold. It will be years before a commercial forest can be started and centuries before the magnificent hemlock, spruce, and pine that once covered it can grow again.

In the 20 years since this prediction was written, conditions have not materially changed on large areas, and the Forest Service has been obliged to plant part of the present Federal holdings.

In the chaparral type of California, a type characteristic of watersheds of critical importance to a large population, hot summer fires destroy the entire cover on thousands of acres every year, often leaving several inches of ash on steep slopes completely exposed to erosion. If the fall and winter precipitation comes as mild, well-sustained rains, studies of the California Forest Experiment Station have shown that a good cover of annuals will come in, and that these, together with sprouts from such crowns of shrubs as remain alive, may be sufficient to hold much of the soil in place. However, these rains are more apt to come as semitorrential downpours before an adequate vegetative cover has become reestablished and then great quantities of soil are washed from the slopes in the rapid unobstructed run-off.

Hoyt and Troxell [22] have compared the run-off of Fish Creek with that of Santa Anita Creek, neighboring watersheds, for the 7-year period from October 1917 to September 1924 when both were covered with forest and chaparral, and then for the 6-year period following a fire in the fall of 1924 which denuded the Fish Creek watershed. In the first year following the fire they found a 231 percent increase in run-off over their estimated normal of 1.07 inches and an increase of 1,700 percent in the maximum daily discharge resulting from the first four storms occurring after the fire. The peak discharge, which was ordinarily 2.5 times the maximum daily discharge prior to the fire, increased to 16.2 times on April 4, 1925.

Figure 1 indicates very clearly the enormously increased flood flows from Fish Creek and an adjoining burned watershed following heavy rains. In this graph the average daily rainfall at Mount Wilson and Santa Anita Ranger Station, in or near these watersheds, are contrasted with the combined daily run-off records of the United States Geological Survey for Fish and Sawpit Creeks (together with the flow in the Monrovia pipe line which comes from Sawpit Creek) for the spring of 1924, before the fire, and of 1925, after the fire.

During the second year after the fire Hoyt and Troxell found an increase of 26 percent above the estimated normal in the run-off from

[21] Glenn, L. C., "Denudation and erosion in the southern Appalachian region and the Monongahela Basin." U.S. Geol. Sur., Prof. Paper No. 72., 1911.

[22] Hoyt, W. G., and Troxell, H. C., "Forests and Stream Flow," Proc. Amer. Soc. Civil Engin., pp. 1037-1066. Vol. 58, August 1932.

Fish Creek and during the 6-year period after the fire an average annual increase of 29 percent. Blaney (op. cit.), however, has attributed this increase to the destruction not of the chaparral, which constitutes 97 percent of the watershed, but of the canyon-bottom forest. Hoyt and Troxell's implied conclusion that in semiarid regions the land should be denuded of forest to increase stream flow cannot be accepted without first considering the certainty of greatly increased erosion and the usableness of the increased run-off.

Hoyt and Troxell themselves point out that under normal conditions erosion in the watersheds of Fish Creek and adjacent creeks was negligible, but that samples of water collected from these streams during 4 months immediately after the fire showed a total sand and ash content of 20 to 67 percent by volume and 6 to 40 percent by weight. They state also that in the first year after the fire the large deposit of silt from the burned-over area caused considerable damage to orchards, railroads, and highways adjacent to the mountains.

Cecil,[23] in discussing the usability of water from southern California watersheds, states:

> The prime requisite in water production is that the water must be usable. This factor is of greater importance than the quantity produced and is vastly more important than a minor increase in the sustained summer flow. Probably 95 percent of the water used for domestic and industrial purposes, outside the city of Los Angeles itself, is pumped (from underground reservoirs), as is also upward of 80 percent of that used for irrigation. * * * The replenishment of these underground reservoirs * * * is of paramount importance. In order that the water finding its way from the mountain areas onto the coastal plain may perform its maximum of use, as much of it as possible should percolate into the underground strata near the months of the canyons from which it issues. For years past, several communities, represented by the water companies supplying them, have spread the flood waters over the detrital cones by means of lateral ditches, increasing the wetted area and materially increasing percolation over that obtaining under natural conditions. The experience of these companies has proved beyond a doubt that, in order that water may be spread successfully and the maximum of percolation secured, it must be free of suspended matter. It is often necessary, during the first run-off of the season, to by-pass to the ocean a varying part of the flood flow. In the case of a watershed that has been run over by fire, the quantity that must be by-passed because of the silt load is many times as great as that under normal conditions.

Reports of the Forest Service indicate that before the 1924 fire on Fish, Sawpit, and Rogers Creeks practically all the run-off of these streams was either used for direct irrigation or went to replenish underground reservoirs as described by Cecil. After the fire, much of the run-off in 1925 was unusable because of erosion debris.

Under the semiarid conditions of southern California it ordinarily takes not less than 5 years for enough vegetation to be reestablished on burned watersheds to serve effectively in handling semitorrential rains. In instances where much of the productive top soil is washed off from the slopes as a result of hard rains in the first year, it will take considerably longer than 5 years to reestablish a closed canopy for the soil.

Farther north in California the foothills of the Sierra Nevada have suffered disastrously from fire. The effect of destruction of cover by fire in the transition between woodland and forest, in Madera County, is shown by experimental plots of the California Forest Experiment Station. In 1929, with 18 inches of the season's precipitation, 747 cubic feet of water per acre ran off the surface of burned plots and

[23] Cecil, G. H. "Discussion of 'Forests and Streamflow.'" Proc. Amer. Soc. Civil Eng., December 1932.

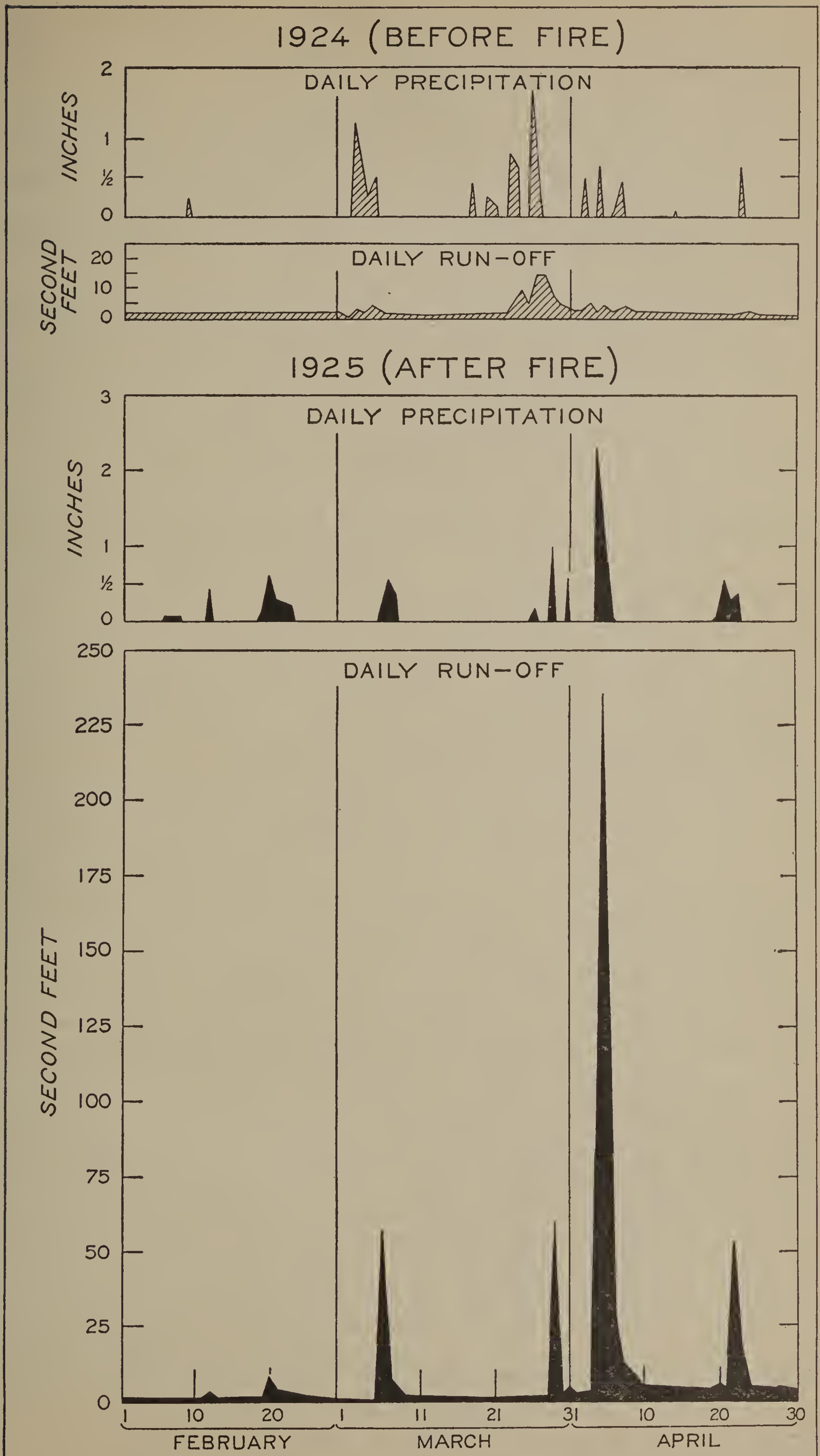


FIGURE 1.—Precipitation and run-off relationship in the Sawpit-Fish Creek drainage, Los Angeles County, Calif., before and after a forest fire occurring in the summer of 1924.

only 4 cubic feet from plots with woodland cover undisturbed. About 4 cubic yards per acre of soil were lost by erosion from the burned plots and only the barest trace from the unburned. Serious erosion is occurring over much of the foothill belt.

In 1929 a fire burned over a considerable portion of the Camas Creek watershed on the Challis National Forest in Idaho. It was evident in the next year that the fire had materially increased erosion. Extensive dry erosion (i. e., trickling of dry soil down steep slopes) and heavy sheet erosion had occurred. This process, begun immediately after the fire, was still going on in 1932.

Serious erosion was also evident on many of the older fire-swept areas. Such examples may be found around Lookout Mountain on the Idaho National Forest which was burned in 1919 or before, and on Sabe Mountain on the Bitterroot National Forest in Idaho, burned in 1910. The exposed roots of the snags and the elevated clumps of bear grass indicate that some 5 inches of soil has been eroded from the burned-over slopes since the 1910 fire.

A torrential rain on the Challis National Forest in 1932, for example, caused excessive run-off to originate on a 1931 burn, resulting in a heavy deposit of sand and debris in tributaries of Loon Creek, sufficient to destroy all possibility of fishing in the stream at least for a number of years. Run-off, the result of a heavy rain in 1932 on a 1931 burn in Richardson and Mann Creeks on the Idaho National Forest, caused deep gully erosion on the slopes and erosion of the stream channel to bedrock. The debris that was swept down these creeks into the Salmon River was sufficient to dam the swift-flowing Salmon River to a depth of 20 to 25 feet and a length of 450 feet, and to cause a new rapids to be formed in the river.

A marked effect of fire on stream flow has been evident under somewhat more humid conditions in the northern Rocky Mountains. In 1919 about 18 percent of the Clearwater River drainage, largely timbered, above Kamiah, Idaho, was burned over, but reclothed rapidly with brush and herbaceous vegetation. The Clearwater River gage records of the United States Geological Survey and data of the Weather Bureau for 10 years, 5 before and 5 after the fire, were analyzed by L. F. Watts, of the Northern Rocky Mountain Forest Experiment Station. These indicated a somewhat higher flow, in relation to precipitation, following the fire, but one much less equable. The average date of peak flow of the Clearwater was advanced by 14 days, in contrast with that of the Salmon River, the drainage of which had suffered much less from fire, which was only 2 days earlier. The average flow of the Clearwater on the peak days was 9.5 percent greater after 1919, in spite of the fact that the highest peak of the period occurred in 1917, as a result of exceptional rainfall in April and May. Furthermore, the April to June run-off increased from 66 percent of the total annual flow to 73.5 percent, and the July to September run-off decreased from 13 percent of the yearly flow to 9 percent. In other words, after the fire the spring flood was 11 percent greater than before the fire, and the summer run-off was 32 percent less. April to June flow is, of course, chiefly the result of surface run-off from melting snow, while July to September run-off results almost entirely from the slow drainage of ground water. The fires appeared to have increased the spring flood flow, but largely at the expense of summer flow.

## LOGGING

Logging in the United States, which includes the removal of other products besides logs, is very variable in the proportion of the trees which it removes and its effects on run-off and erosion. Although a few small areas—mostly farm woodlands—are only culled of a few of the larger or choicer trees at any one time, the common commercial practice on the 10 million acres of forest annually cut over is a very close approach to clear cutting. Through a combination of cutting and fire about 850,000 acres of this are devastated each year—that is, left in such condition that they are incapable of producing another commercial crop of timber within a tree generation. The greater part of this area is almost devoid of standing trees, particularly in the softwood forest regions of the South and West, but some of the eastern hardwood land may have a considerable stand—worthless as a source of wood but very satisfactory as a watershed protection.

Logging alone, if neither preceded nor followed by fire, destroys a smaller proportion of the understory of young trees and shrubby species than of the main stand. However, important areas are still logged by high-powered machinery that drags logs over the ground and wipes out the lesser vegetation. It may even so churn the soil as nearly to obliterate the litter.

On a clear-cut area there is no longer appreciable interception of precipitation by tree crowns, and little high shade to retard snow melt or prevent evaporation from the soil. Temporarily, at least, there is small transpiration. There is, however, a very considerable shading of the ground by slash. This, in a good stand of southern pine, may cover 25 to 40 percent of the ground, and, in such conifer types as Douglas fir, western white pine, southern white cedar, or red spruce, may cover practically 100 percent. After a year or two, this slash itself may become powder dry, but it continues to exert some beneficial effect on evaporation from the soil. It may persist for as many as 10 to 20 years.

In many forest types, clear-cut areas are very abundantly invaded within a season or two by herbaceous plants. These at least serve to check erosion and start to rebuild the extremely important litter.

During a few years after logging, a sloping clear cut or severely cut area will unquestionably erode somewhat. The skid trails produced by power handling of logs in the California pine region, and logging elsewhere, have been found to start erosion.

It is impossible to generalize concerning the time which must elapse before reforestation restores conditions in cut-over land to the point where total run-off and seasonal run-off are essentially the same as in the preceding tree generation. Clear cutting has converted some forest types from all-aged to even-aged ones of probably permanently different character. An even-aged stand, for example, must permit of much less wind movement than an all-aged, once it has raised its canopy well above the ground. A sprout forest will, of course, restore the conditions more promptly than most seedling forests, because of the early vigorous growth.

This is borne out by the results of a watershed study at the Wagon Wheel Gap in the high mountains of Colorado,[24] in which the Forest

[24] Bates, C. G., and Henry, A. J. Forest and Stream Flow Experiments at Wagon Wheel Gap, Colo. Final report. Mo. Weather Rev. Suppl. 30. 1928.

Service and the Weather Bureau cooperated. Here for 9 years, 1910 to 1919, stream flow from two adjacent watersheds was measured under undisturbed conditions; then the forest on one watershed was cut. As the forest was mostly aspen, sprouts of this species took possession of the area in the following year, so that the only real result of the cutting was the removal of the conifers which previous to the cutting were dominant on about a fourth of the area. Despite the fact that the forest cover was so promptly replaced by sprouts, the total yearly run-off was increased by about 15 percent and the summer run-off by about 10 percent. Flood crests were advanced about 3 days and the maximum height of crest averaged 64 percent greater in the cut-over area than in the undisturbed watershed. As previous to logging the height of crest from the cut-over area exceeded the undisturbed area by 6 percent, the net increase amounted to 58 percent. The silt load of the stream after logging increased seven and one half times.

## OVERGRAZING

### FOREST RANGES

Overgrazing on forest lands of the West was without doubt much more wide-spread 25 to 40 years ago than at present. However, serious depletion of the herbaceous and shrubby vegetation under the trees of the forest or in the openings within the forest—the result of past or present overgrazing—still prevails on enormous areas of forest land. The worst of it occurs in the semiarid regions.

If not utilized too closely, the forage produced each year by herbs and shrubs on forested lands is rather well maintained except in the occasional drought year. Investigations of the Forest Service clearly indicate that perennial herbaceous plants, principally grasses, were once the chief forage on most forest ranges, and this is still true except where these plants have been depleted. Studies also show that where trees do not grow in sufficiently dense stand to form a closed canopy, such as the woodland type, and also in openings in the denser forests, these perennial herbaceous plants if still present, are the chief erosion-control agent.

Overgrazing disturbs the forest cover chiefly in two ways: first, by consuming more of the herbage of the more palatable plants than they can withstand, and, second, by increased trampling. Under such overutilization, the palatable forage plants are grazed closer and closer, and their vigor is sapped. As these plants produce less forage and their stand is thinned, the less valuable plants are grazed more severely until they, too, are thinned. Studies by the Forest Service show that there are many areas now producing not more than 20 to 30 percent of the forage of which they once were capable, and under such conditions erosion is usually severe.

Conditions in central Utah as a result of past abuse illustrate this depletion. Good stands of wheatgrass and bromegrass in the openings of the aspen and subalpine forest types of the higher mountains were once capable of supporting a cow for a month on less than 2 acres. Remnant areas indicate that soils were deep and rich. Overgrazing depleted the open areas until they supported chiefly annual grasses and weeds, of which 10 acres or more are required to furnish a cow feed for a month. With such an inadequate protective cover several inches of topsoil has been eroded away over extensive areas.

Forsling [25] has pointed out that depletion of forage is accompanied by severe soil losses without any material gain in the total water obtainable from watersheds in this region. He studied conditions on two subalpine watersheds of about 10 acres each at the head of Ephraim Canyon, Utah. On watershed A, a 16 percent cover, mainly of annuals, was maintained from 1915 to 1920, but was improved gradually until in 1924 it reached 40 percent, made up chiefly of perennial grasses and weeds. In this condition it was maintained through the 6-year period 1924 to 1929. On watershed B, used as a check, a 40 percent cover, largely of perennial grasses and weeds, was maintained for the full period 1915 to 1929. Table 7 presents the comparative data from these two watersheds.

TABLE 7.—*Comparison of surface run-off and sediment removed from two watersheds under different densities of vegetative cover*

| Period and watershed | Vegetative cover | Total rainfall [1] | Total surface run-off | Run-off per inch of rainfall | Sediment removed per acre | Sediment per inch of rainfall |
|---|---|---|---|---|---|---|
| 1915–20: | *Percent* | *Inches* | *Inches* | *Inch* | *Cu. ft.* | *Cu. ft.* |
| Watershed A | 16 | 30.45 | 1.5084 | 0.0495 | 802.9 | 26.37 |
| Watershed B | 40 | 32.01 | .2529 | .0079 | 148.0 | 4.62 |
| Difference | | | | .0416 | | 21.75 |
| 1921–23: | | | | | | |
| Watershed A | 16–40 | 17.20 | .7618 | .0443 | 315.1 | 18.32 |
| Watershed B | 40 | 17.43 | .2153 | .0124 | 111.9 | 6.42 |
| Difference | | | | .0319 | | 11.90 |
| 1924–29: | | | | | | |
| Watershed A | 40 | 25.21 | .4914 | .0195 | 114.9 | 4.56 |
| Watershed B | 40 | 25.96 | .2271 | .0087 | 46.4 | 1.79 |
| Difference | | | | .0108 | | 2.77 |

1 All storms coming as rain, or rain with snow and hail, and exclusive of storms that were snow only.

It is significant that the difference in surface run-off in summer rains between the two watersheds is 75 percent less after watershed A reached a reasonably good vegetative condition. It is excessive run-off from summer rainstorms that causes the destructive floods in this locality. In both periods the records available indicate that total surface run-off from summer rains amounted to less than one twentieth of the total annual surface run-off from the watersheds. Annual soil losses from watershed A in its depleted condition were over 8 tons per acre, nearly 85 percent of which was the result of summer rains. Approximately 133.8 cubic feet of soil per acre were removed annually from watershed A in the 1915–20 period and only 19.2 cubic feet per acre per year in the 1924–29 period. The difference in sediment removed between the watersheds was strikingly reduced following the improvement in vegetative cover—87 percent between the first and last periods.

Destructive floods have occurred in Utah in the last 10 years in the thickly populated area near Salt Lake. Studies made by Prof. Reed W. Bailey [26] of the Utah Agricultural College, in cooperation with the Intermountain Forest and Range Experiment Station and

25 Forsling, C. L. A Study of the Influence of Herbaceous Plant Cover on Surface Run-off and Soil Erosion in Relation to Grazing on the Wasatch Plateau in Utah. U.S.Dept.Agr.Tech.Bul. 220. 1931.

26 Bailey, Reed W. Statement in hearings before the House Committee on the Public Lands on H.R. 11816, 72d Cong., 1st sess. 1932.

the Utah State Land Board, have shown that the 75-foot or deeper channel cutting and the enormous amounts of waste debris deposited by these recent floods were far in excess of any earlier flood action in that locality since the geologic Lake Bonneville ceased to exist some 30,000 or more years ago.

After the floods of 1930 the governor's special flood commission established the fact that the heavily silt laden flood waters had collected chiefly on small areas of private land at the heads of the drainages where the vegetative cover had been destroyed or seriously depleted by overgrazing, fire, and to some extent by logging. These areas are badly gullied and the surface soil has been stripped away through sheet erosion. Slopes, too steep for grazing, that at intermediate elevations make up the greater part of the mountain face, bear a substantial brush or forest cover. No gullies originated on these densely vegetated slopes, where the thick litter cover and the large humus content in the surface soil permitted effective penetration of water and restrained the surface flow sufficiently to prevent undue soil or water losses.

There are in the West large areas of coarse readily erosible granitic soil. This is especially true of the Boise River drainage of southwestern Idaho where the underlying granite easily disintegrates, crumbling to coarse sand and fine gravel which combined make up 80 percent or more of the total soil mass. These soils are so extremely loose that where the plant cover becomes scarce the soil is readily swept off as sheet erosion. In the subalpine forest zone 4 to 8 inches of the black surface soil has been removed, and at lower elevations practically all the surface soil has been lost. Heavy run-off quickly causes the formation of gullies from a few inches to several feet deep. Loose soil on the edges of the gullies soon crumbles, and within a year or two after being formed many of the smaller gullies have so smoothed over as to appear to be healing when actually they are not.

Past overgrazing on practically all of the open areas within the forest and on some timbered areas of the Boise River watershed is known to have greatly reduced the protecting vegetative cover and trampling of these inadequately protected soils has often set in motion a downhill movement of the soil which is greatly accelerated by run-off from torrential rains.

Of nearly 350,000 acres examined by the Forest Service, more than 80 percent is in timber and heavy brush, which occupies all the north and parts of the south slopes. Fifty-six percent of the timber or brush areas subject to grazing has suffered sheet erosion, and 9 percent additional has suffered gully erosion as the result of overgrazing. Of the 53,000 acres of timber and brush areas too dense or on too steep slopes to permit grazing, only 14 percent had suffered sheet erosion and but 2 percent additional light gully erosion.

In contrast to these heavily grazed areas on the Boise watershed, only about 5 to 10 percent of similar locations and exposures on the game preserve on the nearby Payette drainage, subjected for many years only to light grazing, have lost the top layer of black soil. Beneath 1 to 3 inches of litter in open areas and 1 to 6 inches in the dense timber, the preserved soils contain 4 to 11 percent organic matter. This compares with 1 to 2 percent on the raw eroded soils, on which there is no measurable depth of litter.

WOODLAND PASTURES

In pastured farm woodlands of the Middle West, studies by the Central States Forest Experiment Station show that overgrazing results in the destruction of the sprouts of hardwood timber species, and that trampling of the livestock tends to destroy the litter and compact the soil, making it less receptive of precipitation and subject to erosion. Under extreme use, such as occurs in the Corn Belt where many farm woodlands are used as much for shade as for the feed they produce, practically the entire understory of vegetation and the litter covering the soil has been destroyed. When such a situation has developed the topsoil is invariably lost. Bates and Zeasman [27] have shown, on comparable soils, that, from a plot in pastured oak woodland with a slope of 38 percent, 13 percent of the rain ran off, while from a dense unpastured oak forest with a slope of 42 percent only 0.2 percent ran off, and only 2 percent from open unpastured oak woods with a slope of 49 percent ran off.

Auten (op. cit.) has shown in his studies of soil conditions in grazed and ungrazed woods in Ohio that the top 9 inches of soil in the grazed areas averaged 15 percent heavier than similar topsoil from ungrazed woods. This increase in density is a reflection of the greatly reduced capacity of the grazed soils to absorb water.

The work of Stewart [28] reveals the same tendency in New York State for long-continued grazing use to reduce permeability and water storage of soils.

SMELTERS

Fumes from smelters and other industrial plants may completely destroy or injure forest and other vegetation. Destruction by smelter fumes is found near Ducktown, Tenn., Kennett, Calif., Anaconda and Butte, Mont., and in the vicinity of a number of other smelters located within forested areas. Large areas around them demonstrate to a superlative degree the debt mankind owes to vegetation for its influence on surface run-off and erosion and the price we must pay when we destroy it. At Ducktown, an area of from 10 to 12 square miles around the smelters has become denuded of natural vegetation with the exception of occasional clumps of sage grass and wild smilax. Bordering this barren region is one varying from 1 to 5 miles in width, covered with sage grass, vines, and a few stunted shrubs and small trees, the latter often with dead tops. Beyond this border of almost treeless vegetation the country is not heavily wooded for some distance, the growth being unthrifty and trees with dead or dying tops being numerous.

Glenn (op. cit.) states that the annual rainfall in the region is 50 to 60 inches, and often torrential, so that during the downpours soil surfaces almost literally melt away. The wasted soil accumulates along the stream courses. He states further:

> On Potato Creek this waste has been accumulating for a number of years at the rate of a foot or more each year, and has been built into a flood plain from 100 to 300 yards wide, in which telephone poles have been buried almost to their cross arms and highway bridges, roadbeds, and trestles have either been buried by the debris or have been carried away by floods. . . . The normal flow of Potato Creek is said to be only about half as large as it used to be, and there can

[27] Bates, C. G., and Zeasman, O. R. Soil Erosion, Wisc. Agric. Expt. Sta. Res. Bul. 99. 1930.
[28] Stewart, G. R. "A study of soil changes associated with the transition from fertile hardwood forest land to pasture types of decreasing fertility." Ecological Monographs, January 1933.

be no question that a much larger part of the rainfall now finds its way immediately into this stream and is carried off in floods, leaving a much smaller part to soak into the ground to supply the wells, springs, and streams during periods of dry weather.

Near Kennett, Calif., all vegetation has been destroyed on an area upward of 67,000 acres and partial destruction has occurred on 86,000 acres additional. Without the protecting vegetative cover, the surface soil of the denuded portions was soon washed off, exposing an inert subsoil which continues to wash and gully at a rapid rate. Munns[29] estimated a total of more than 35 million cubic yards had been removed from the Kennett area in 10 to 15 years. Conditions are very similar in other smelter areas.

### CLEARING FOR AGRICULTURE

Hundreds of millions of acres once in forest have been cleared for crop production. This was a natural process in the settlement of the United States. At the time many were cleared little was known of the productive capacity or the erosiveness of the soils, and it is natural that many areas have later proven to be unsuited for permanent agricultural use. In the section of this report entitled "Agricultural Land Available for Forestry", the Bureau of Agricultural Economics estimated that today there are over 50 million acres of cleared land, which, abandoned or idle, are available for reforestation. Of these probably 11 million will require artificial reforestation. Present trends indicate an additional abandonment of some 25 or 30 million acres of potential forest land in the next 20 years.

These areas, abandoned or in process of abandonment, have largely passed such usefulness as they had for crop production. Many owe their abandonment to loss of productivity through erosion of the fertile topsoils and in some instances of large amounts of the subsoil. They are found most often in hilly and mountain regions, in regions of more level topography but having soils which erode with extreme ease, and in regions where the soils do not erode readily, but where the topsoil is so shallow and the subsoil so unproductive that the loss of a few inches of soil by erosion renders them practically worthless. These lands are widely distributed east of the Great Plains, but are found in parts of the West as well.

Through the adoption of contour plowing, terracing, crop rotation, and other suitable methods of cultivation doubtless much of the slightly eroding agricultural land can remain in crop production or in pastures. Such land is beyond the scope of this report. On most of the 50 million acres of abandoned lands, however, the loss of soil productivity has reached such proportions that cropping methods cannot be expected to overcome the active erosion and hazards of agricultural production. As Bennett[30] has stated:

> When the mellow topsoil is gone, with its valuable humus and nitrogen, less productive, less permeable, less absorptive, and more intractable material is exposed in its place. As a rule this exposed material is the "raw" subsoil, which must be loosened, aerated, and supplied with the needed humus to put it into the condition best suited to plant growth. This rebuilding of the surface soil requires time, work, and money. In most places this exposed material is heavier than

[29] Munns, E. N. Erosion and Flood Problems in California. Calif. State Bd. Forestry Rpt. to the Legislature 1921 on Sen. Con. Res. 27. 1923.

[30] Bennett, H. H. "Part I. Some Aspects of the Wastage Caused by Soil Erosion." Pp. 1–3. Dept. Agr. Circ. 33, "Soil Erosion a National Menace." (H. H. Bennett and W. R. Chapline) 1928.

the original soil, is stiffer, more difficult to plow, less penetrable to plant roots, less absorptive of rainfall, and less retentive of that which is absorbed, and apparently its plant-food elements frequently have not been converted into available plant nutrients to anything like the degree that obtains in the displaced surface soil. . . . Such raw material must be given more intensive tillage in order to unlock its contained plant food, and on much of it lime and organic manures will be needed in order to reduce its stiffness sufficiently to make it amenable to efficient cultivation, to the establishment of a desirable seed-bed tilth. It bakes easier and, as a consequence, crops growing on it are less resistant to dry seasons, because of rapid evaporation from the hardened surface, and the many cracks that form deep into the subsoil to enlarge the area exposed to direct evaporation. Crops also suffer more in wet seasons because the material becomes more soggy or water-logged than did the original soil. On much of it both fertilizer and lime will be required for satisfactory yields.

While these difficulties of tillage and the lowered productivity are being attended to by the farmer in those fields not yet abandoned, the unprotected fields continue to wash. Unfortunately the farmers in many localities are doing little or nothing to stop the wastage and much to accentuate it.

Even on moderate slopes the soil losses from the cultivated fields on certain soil types, under unfavorable climatic conditions, are enormous. Forest Service studies at Holly Springs, Miss., in the loessial-soil belt, show that a single torrential rain falling on a cornfield having a 10 per cent slope washed soil from a study plot at the rate of 23 tons per acre. Preliminary results show that under such conditions only 2 to 3 years are required to wash away 1 inch of topsoil. These data, substantiated by observations, indicate that the cultivable life of these upland soils ranges from 5 to 20 years. Yet the serious danger of erosion from the cultivation of fields of slight slope in this region which have readily erosible soils is not so generally recognized and many such fields are being cleared and plowed to take the place of other fields which have lost their productivity. Bennett points out (op. cit.) that "some soils can not be cultivated without steady decline due to erosion, even where the slope does not exceed 1 or 2 percent. The Knox silt loam, for example, is such a soil. On this soil erosion goes on in all tilled fields where there is any slope whatever."

The high run-off from slight slopes is further shown by Duley and Hays[31] in their studies in Kansas. They found run-off increased rapidly as the slope increased from 0 to 3 percent grade. Over 63 percent ran off with a 2 percent grade in their experimental tank. The increase in run-off was then very slight for each 1 percent of increase in slope, reaching about 86 percent with a slope of 20 percent grade. Erosion, on the other hand, increased gradually until the slope was about 4 percent; then the increase was found to be more rapid up to about 7 or 8 percent, after which there was a still greater increase in the rate at which the soil was removed from the plots.

If level agricultural land were scarce in the United States, and there were a great need to increase crop production, very intensive farm management could unquestionably be applied to rather steep slopes to meet the situation. Under existing circumstances, however, it seems likely that clearing new ground on slopes of over 10 to 15 percent is destined eventually to swell the area of abandoned land and add to the problem of reclaiming gullied land by reforestation.

The process of planting trees on actively eroded land is not simple. Preliminary measures, in the form of temporary terracing, "plowing

[31] Duley, F. L., and Hays, O. E. "The Effect of the Degree of Slope on Run-off and Soil Erosion." Jour. Agr. Research, vol. 45, no. 6: 349-360. 1932.

in" of gullies, planting vines and herbaceous plants, will often be needed where the brush and forest vegetation do not naturally reclothe the area quickly enough to check the erosion. Considerable research on such methods is needed, and on the most effective type of forest to establish on the depleted soils, now incapable in many instances of maintaining the original forest cover.

## WATERSHED-PROTECTION FORESTS IN OTHER COUNTRIES

In many countries "protection forests" are defined by law. They are forests the main object of which is to help to prevent avalanches and snowslides; check or reduce soil erosion; retard snow melt; preserve favorable conditions of run-off; stabilize shifting sands; protect other forests or property from wind, or contribute to the national defense. In short, the definition embraces all the many indirect benefits which the forest exerts upon water, soil, and climate.

Disastrous floods, silting of navigable channels, and destructive soil erosion gave impetus to the development of forest policies in numerous countries during the nineteenth century. It was readily recognized that these evils were greatly aggravated by denudation of forest lands in the mountains and along the streams. In Europe policies of alienating public forests, which had been adopted following the French Revolution, were halted. Instead, the public began to extend its ownership of forest lands, largely in the mountains, for the purpose of restoring and protecting the forest cover.

At the same time, governments began to impose restrictions upon the management of privately owned forests, where their preservation was deemed essential for protecting soil and water. As the years have passed, more and more countries have adopted such restrictions, until now the list includes practically all the countries of Europe, as well as Japan and a few others.

The scope of these restrictions varies widely, but in general the laws require that classified protection forests, regardless of ownership, be handled in such a manner that the forest cover will be maintained. Clearing of the land is usually prohibited, and timber cutting and grazing are generally subject to a greater or less degree of supervision by public authorities. The reforestation of denuded land and construction of engineering works to check or prevent erosion or control torrents are commonly provided for, partly or wholly at public expense. In Switzerland, for instance, more than $57,000,000 was spent on stream control works between 1862 and 1923. Nearly one half of this cost was borne by the Federal Government, and most of the remainder by the cantonal governments. Similar policies have been pursued by France, Italy, Austria, and Japan, as well as by other countries. Either by cash payments or by reduction in taxes, many of the countries reimburse the land owners, at least partially, for any loss in income which they may suffer as a result of the restrictions.

In case an owner is unwilling to retain his forest and manage it in the manner prescribed, it is commonly provided that the public shall buy him out. France and several other countries have a definite policy of acquiring private forests and denuded land in mountain districts, for the purpose of safeguarding protective values. Within the last few years very large-scale programs of public acquisi-

tion and reforestation, mainly of protection forests, have been under consideration in a number of countries. Shortly before her recent revolution, Spain appropriated $19,000,000 for this purpose. France has been considering an even larger program.

Public forests that have protective value are, of course, almost universally managed so as to preserve and increase their protective effect. Soviet Russia has excepted forests that lie along or on the headwaters of important streams from the present policy of liquidation of timber values which is said to be applied to other forests. Just as in the United States, a large proportion of the public forest area in many countries, particularly that belonging to provincial or national governments, is in mountain regions and consequently of high protective value. The less accessible mountain forests naturally were the last to be sought by private owners. This is less true of the communal forests, which are generally located fairly close to settlements. Forests belonging to mountain communes, however, such as many of those in Switzerland, Austria, France, and Spain, also have high protective value and are managed accordingly, generally under the supervision of the national governments.

More detailed information on the foreign legislation dealing with protection forests is given in the section on "Public Regulation of Private Forests."

## CLASSIFICATION OF WATERSHED PROTECTION INFLUENCE OF FORESTS OF THE UNITED STATES

With a view to determining the relative importance of forests in the regulation of stream flow, in water supplies, in erosion control, or in influencing other watershed values, the forest areas of the United States have been classified into three groups: (1) Those of major influence; (2) those of moderate influence; and (3) those of slight to no influence. It is recognized that adequate scientific data and results are not available for an absolute classification. In classifying the forest lands, however, the possible application of such research data as are available has been considered for all areas, and these data have been supplemented by field observations and study of all available records. In order that the interpretations would be most useful, general observational surveys were supplemented by specific examination of representative areas. The classifications represent the best combined judgment that the Forest Service could bring to bear on them.

Forests considered as of major influence included those occurring on steep slopes subject to heavy or concentrated rainfall; on areas with excessive and rapid snow melt; and on areas having unusually erosible soils, where in the absence of the forest cover serious damage would be apt to be done to soil or other values of the watershed itself, or to land, improvements, navigation, or other values. In a number of localities, particularly in the West, where the demand for water is unusually great and where because of scant rainfall it is necessary to conserve as much of the stream run-off as possible, the forest cover, even though far from a complete canopy, has been classed as of major influence. These forests include many areas of the woodland type, where disturbance of the forest cover has caused or would cause abnormal erosion and endanger water conservation through the exces-

sive silting of reservoirs, or of gravel beds into which run-off is sunk for underground storage and later pumping, as in southern California.

Forests considered as of moderate influence include those occurring on moderate slopes, on areas of moderate or scant rainfalls, on soils which do not erode readily, and on areas where the forest cover quickly reclothes the land in case fire, lumbering, or other cause depletes the cover.

Forests considered as of slight to no influence include those areas where it appears that the forest exerts only a poorly defined or very indirect influence upon streams, water supplies, or erosion. Forest areas classified as slight include those more or less level areas occurring on old lava flows, or on deep sandy soils through which precipitation readily percolates, and from which erosion is very slight. Likewise forests occurring on poorly-drained and nearly level areas have been considered as of slight influence.

In order to indicate these broad classes on the maps accompanying the report it has been necessary to include with a larger area of another classification many small areas not strictly classifiable as shown. As intensive a classification as possible was made, however, and is shown diagramatically on the regional maps whenever the areas were large enough to be recognized.

## DRAINAGE BASINS OF THE UNITED STATES

Forest conditions throughout the United States differ so widely, their influence on watershed problems is so varied, and the importance and character of the watershed problems so varied, that for purposes of even somewhat detailed description the country has been divided into drainage regions. In part these are purely geographical, in part they represent large drainage basins. Figure 2 indicates the division of the United States into these regions.

For each of the drainage regions the influence of the forest is represented. The present condition of the forest, and its effectiveness in exerting the influence of which it is capable are also indicated.

## NORTHEASTERN DRAINAGES

The northeastern drainages as here covered include all those streams which flow into the Atlantic Ocean north of the Potomac River, excepting tributaries of the St. Lawrence River. In considerable part they include the two regions discussed elsewhere as the New England and the Middle Atlantic States (fig. 3).

### CLIMATE AND PHYSIOGRAPHY

Compared with many portions of the United States where watershed and stream flow problems are also acute, the northeastern drainages receive abundant rainfall—from 30 to 50 inches annually at most points, and up to 75 inches on some of the higher mountains. There are no conspicuously wet or dry seasons; the average monthly rainfall during the wettest months of the year is rarely more than double that of the driest months.

In spite of the normally high and equably distributed rainfall, however, deficiencies and irregularities in rainfall are by no means uncommon. In 1930 for example, the southern and central portions of the

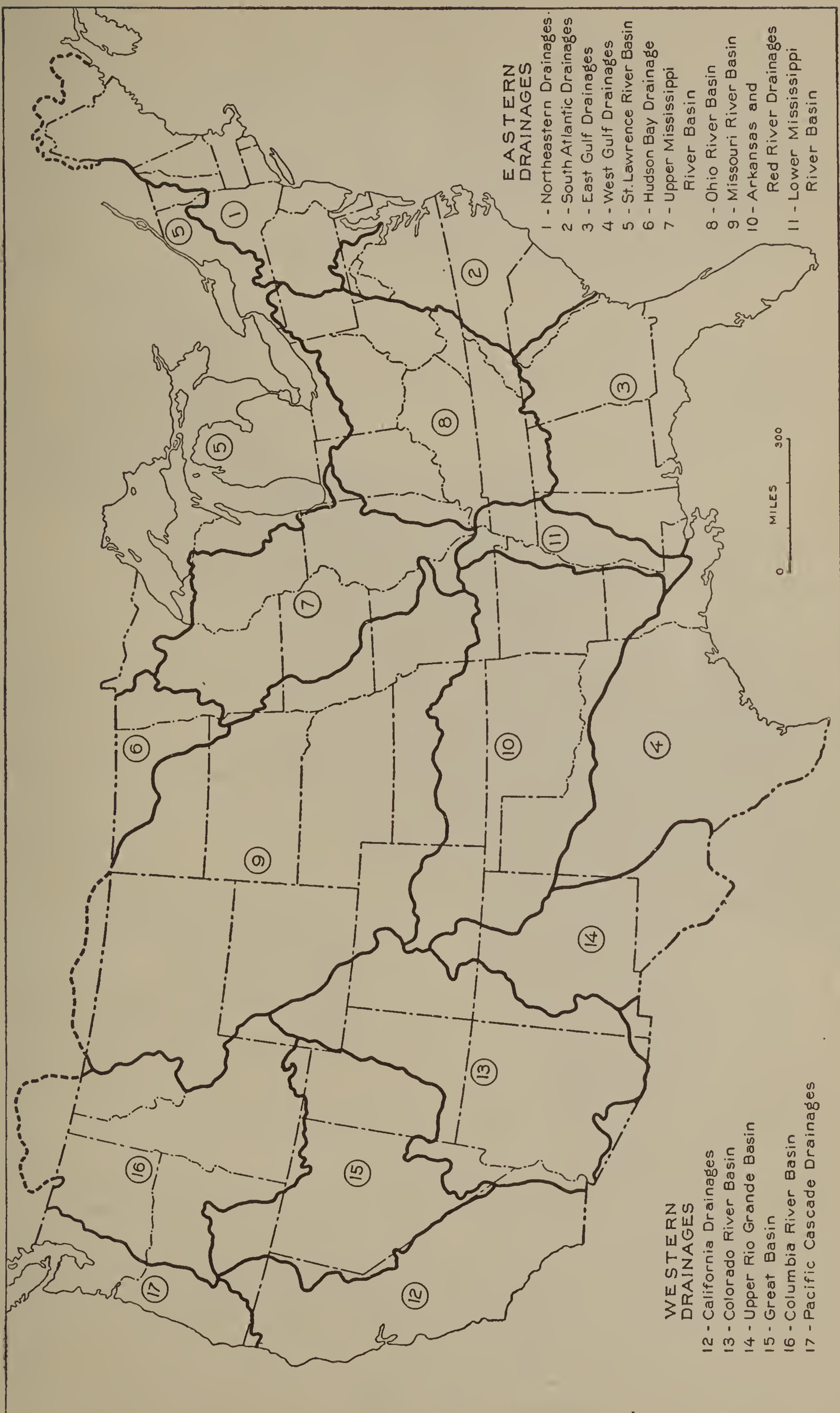


FIGURE 2.—Major drainage basins of the United States.

region were visited by a drought of extraordinary length and severity. Maryland received only 56 percent of the normal rainfall in that year, Delaware 65 percent, and Pennsylvania 68 percent. Although this drought was a record one for the region as a whole, in central New England it was exceeded by the drought of 1929. Extremely heavy downpours in brief periods of time are also characteristic of the regional rainfall. The middle Atlantic coast, with its center in northeastern New Jersey, is particularly subject to very heavy precipitation; between 1843 and 1929 this region experienced 102 storms of

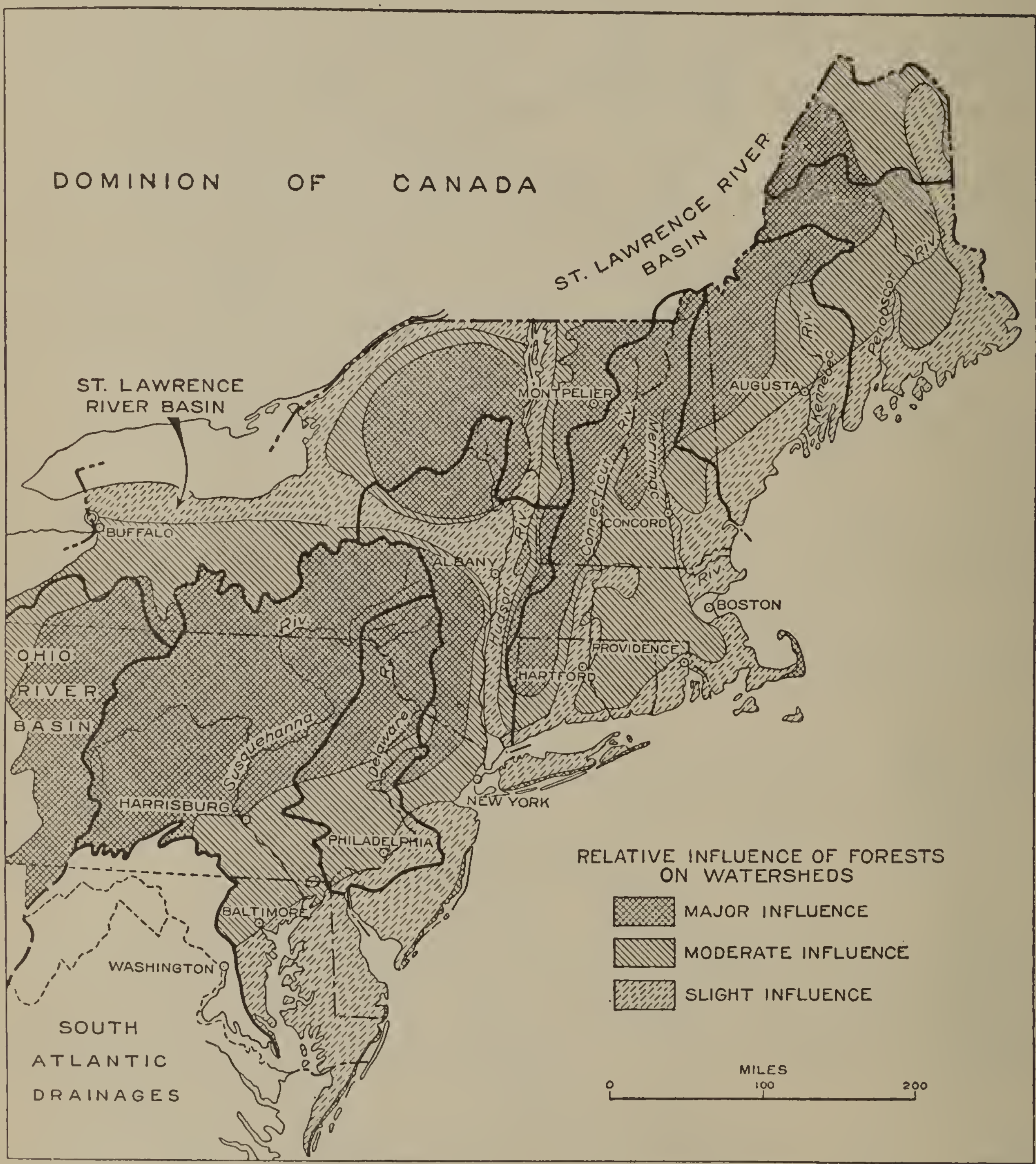


FIGURE 3.—Northeastern drainages, and lower portion of St. Lawrence River Basin.

5-inch precipitation in 24 hours. Two storms during that period produced 15 inches of rain in 24 hours. Annual snowfall ranges from an average of 14 inches at the Delaware capes to 150 inches in the Adirondack Mountains of New York. It is from 50 to 100 inches throughout Maine, but in the southern part of the region reaches 50 inches only at the higher elevations. Snow lies on the ground for one to five months, depending on latitude and altitude.

Elevations above sea level are less than 500 feet throughout the coastal plain and much of the adjacent piedmont province, and in

the southeastern half of Maine. They exceed 3,000 feet in the Allegheny Mountains, 4,000 feet in the Catskills, 5,000 feet in the Adirondacks, and 6,000 feet in the White Mountains. Differences in elevation of 1,000 to 1,500 feet between ridges or plateau tops and the adjacent valleys are common.

Glacial soils are characteristic of the region as far south as northern Pennsylvania and New Jersey. These include considerable sandy areas. Sands are of course characteristic of the coastal-plain province from the tip of Cape Cod to the shores of Chesapeake Bay. On the whole, however, heavier soils predominate. The soil mantle becomes extremely thin at the higher elevations and there are some areas of practically bare rock, either outcrops or of glacial deposition.

### WATERSHED AND STREAMFLOW PROBLEMS

There are five major watershed and streamflow problems in the region, in the solution of which the forests of the region may play an important role. These, in their order of importance, are urban water supplies, water power, navigation, erosion, and floods.

#### URBAN WATER SUPPLIES

The problem of obtaining adequate water supplies for municipal use—both for domestic and industrial purposes—has received much attention in the Northeast, because of heavy concentrations of population. The metropolitan districts of Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, New Jersey, and Maryland contain over 15 million people. Forty percent of the population of the last four of these States is concentrated about the cities of New York, Philadelphia, Baltimore, and Washington. The Regional Planning Federation of Philadelphia estimates the present consumption of water in Philadelphia and the surrounding territory to be 467 million gallons daily, and that of 50 years hence at 800 million gallons. More than half of this consumption is by industries. Using as a basis the per capita consumption of Philadelphia, 132 gallons daily, water requirements for the metropolitan centers of the region may be estimated in excess of 2 billion gallons daily.

In the Northeast much of the water for urban consumption comes from surface streams. The larger available rivers are for the most part rather heavily polluted, at least in the lower reaches, by mining, pulp, and industrial waste, and by the sewage of scores of communities. Although practically any polluted surface water may be so cleansed as to be clear, palatable, and normally safe, the consequences of a failure in the treating process are so serious, and public prejudice against the use of polluted streams is so great, that a clean raw water supply is preferred by most cities. Largely for this reason, the city of Boston is planning a dam and reservoir 60 miles from the city, and New York City obtains part of its present water supply from a reservoir located 92 miles away. New York City's investment in four dams, behind which 166 billion gallons of water may be stored, exceeds $66,000,000. The communities of northern New Jersey plan a high-level development costing about $45,000,000 exclusive of the distributing systems, and according to the Water Policy Commission of New Jersey even this huge project will not meet the needs of these communities beyond 1960. Philadelphia draws its water supplies

from the Delaware and Schuylkill Rivers. Of the Schuylkill River the Regional Planning Federation of Philadelphia states: "It is doubtful if there is a river of similar size in the United States, undeveloped by storage, which is utilized more intensively and completely for water supplies than the Schuylkill."

Even underground water supplies have felt the heavy drain of human use. The coast resorts of southern New Jersey, for example, which obtain municipal water supplies largely from deep wells, have found the ground water table seriously lowered in recent years, and face the threat of an invasion of salt water from the ocean. The draught on the underground water supplies of Camden and the adjacent territory in New Jersey is said to be increasing at the rate of about 3 percent a year.

The droughts of 1929 and 1930 emphasized the seriousness of the municipal water-supply problems in the Northeast. In 1929 several communities near Boston, having independent water supplies normally adequate to their needs, were obliged to tap the already depleted metropolitan district water system with temporary pipe hastily laid on the surface of the ground. An official of the Maryland State Department of Health said of the 1930 drought in his State:

> Few things have more seriously affected our lives, our health, or our peace of mind, than did the drought of 1930 * * *. Nevertheless, the results of the long-continued drought have not all been bad. Faced with a disastrous shortage, if not a complete lack of water, people in towns fed by public water supplies, and others in settlements or on farms drawing water from wells, springs, or cisterns, have been compelled to think and devise means of escape.

Equable streamflow for domestic and industrial use remains a major public problem of the northeastern United States.

### WATER POWER

Water power has been extensively developed in the Northeast. It was the basis for the original manufacturing supremacy of New England. In Maine, 70 percent of all power for industries and public utilities is developed from streams. The horsepower developed by five plants recently constructed on a comparatively short stretch of the Connecticut River aggregates 350,000. In 1931 New York produced more power from her streams than any other State in the Union except California, and nearly twice as much as the State third in rank—North Carolina. At three points on the lower Susquehanna River are power plants with capacities of 158,000, 170,000, and 378,000 horsepower, respectively, and the electrical energy developed on the entire Susquehanna is about two thirds that which will be developed on the Colorado River at the Hoover Dam. According to the figures of the U.S. Geological Survey for January 1931, more than 30 percent of the Nation's water power is produced in the Northeast.

In the absence of a natural uniform flow, power plants must rely upon costly reservoirs or else resort to supplementary steam power. Streams from forested watersheds tend toward uniformity. Irregularity in stream flow made necessary the Conowingo Dam on the Susquehanna River in Maryland, which cost $52,000,000.

### NAVIGATION

A third watershed and stream-flow problem of great local magnitude in the Northeast is the maintenance of navigation. The annual

report of the Chief of Engineers, U.S. Army, shows that in 1929 commercial tonnage on the principal rivers of this region was considerably greater than that transported on the Mississippi River, from Minneapolis to New Orleans. In order to maintain a ship channel of proper depth in the Delaware River to the port of Philadelphia, the War Department between 1920 and 1931 spent $31,500,000, chiefly in dredging, and from Philadelphia to Trenton, an additional $800,000. Dredging the Schuylkill River at Philadelphia has cost the Federal Government $1,300,000 in the same period. The maintenance of these and other ship channels of the Northeast in the face of continued deposition of silt and similar material brought down by the streams, is closely related to the fourth major stream flow and watershed problem of the region.

### EROSION

Soil erosion resulting from a rainfall of 35 or more inches a year, at times concentrated in very brief periods, depends on three main factors: Degree of slope, character of soil, and vegetative cover. Of the forested area on the northeastern drainages, 10 percent has been classified as very steep, 22 percent as steep, 15 percent as moderately steep, 40 percent as gently rolling, and 13 percent as level. The streams of northern New England are relatively free of silt and debris, showing that erosion is not particularly serious. It is more than a coincidence that even in the mountainous portions erosion is slight and percentage of forest cover high. In southern New England, Pennsylvania, and northern New Jersey erosion is prevalent. Here the soils are heavier, and there is a greater proportion of agricultural land.

Erosion is unquestionably most severe on agricultural lands exposed by plowing and clean cropping. Farm-land abandonment has been general throughout the northeastern States; only a single small county in one State—New Jersey—has escaped it. In Hamilton County, N.Y., there has been since 1900 a decrease of 78 percent in the area of cultivated land; in Cameron County, Pa., the decline is 63 percent; in Berkshire County, Mass., the decline is 60 percent. For the northeastern drainages as a whole the acreage of crop land abandoned in the past two decades amounts to over 10,000,000 acres. Some of these lands have developed a sod which is holding the soil in place. Many others lack cover, and are eroding seriously.

How much of the present decline is due to decreased fertility of farm land is not known, but the condition of some abandoned fields shows that erosion was at least partly responsible. Although shoestring gullies in abandoned fields on steep slopes are not uncommon in any State, sheet erosion is far more prevalent than gullying. In many parts of New England and New York, for example, the widespread occurrence of gravel and stones on the surface of fields is evidence that the finer soils have been removed by erosion following clean cultivation. Several thousand acres of formerly excellent agricultural land in northern New Jersey have gone entirely out of cultivation as a result of such erosion.

Clear cutting of the timber and burning of forest land exposed the soil, at least temporarily, to erosion. The more complete the ex-

posure, the more nearly are conditions reduced to those existing on clean-tilled land.

Erosion is unquestionably responsible for the major part of the expenditure to maintain channels in the Delaware River, as has been previously described. Erosion has its effect on water storage, for municipal supplies and power. In 1915 the State forester of Maryland described as follows the results of erosion along the Patapsco River in his State:

> Between Relay and Alberton, a distance of 11.4 miles, there are 10 water-power developments, 8 of which are now in operation. Power for these plants is furnished by the Patapsco River, and its value for that purpose is measured by the evenness of flow and freedom from silt * * *. The steep slopes along the river that have been cultivated in years past have largely contributed to the accumulation of silt which has collected behind the dams built for storage purposes and has clogged the river channels, increasing the frequency of floods and carrying immense quantities of silt into the upper Patapsco near Baltimore, requiring the expenditure of large sums of money for dredging.

Another erosion problem of considerable local importance in the northeast is not created by water, but by wind. The shores of both the Atlantic Ocean and the sheltered bays behind sandy spits are used for recreation by enormous numbers of people. In places drifting sands have seriously interfered with this use. Efforts have been made to control the dunes on Cape Cod and at various other places along the coast, but individual effort has not been effective in the face of a problem common to many owners of shore properties. The need for studied and concerted effort is emphasized by the constant increase in number of the recreationists. Not less than 500 miles of coast line is involved in varying degree.

## FLOODS

Low water during the summer in streams used for municipal supplies, for generation of power, and for navigation, is scarcely more of a problem in the region than is high water at other times of the year. Parts of the northeast have suffered very greatly from floods. The 1907 report of the Water Supply Commission of Pennsylvania stated that:

> Pennsylvania is one of the worst sufferers from floods among the eastern States * * *. It is not alone the large streams on which damage has been wrought, for many of the smaller streams overflow their banks with disastrous results, and in such cases the damage has been increased by the failure of dams or embankments, thus releasing the additional water into the already overflowing channel.

The North Branch of the Susquehanna River has repeatedly inundated the city of Wilkes-Barre, and the floods of 1902 and 1904 in this stream destroyed $1,300,000 worth of bridges alone, as well as millions of dollars worth of other property. According to a report made in 1931 by the New Jersey State Water Policy Commission, a repetition of the 1903 flood in the Passaic River would today cause a damage of over $42,000,000. Such floods in the Passaic may be expected only about once in 200 years, but a flood causing $1,000,000 worth of damage will occur on the average once every 5 years, and one causing over $2,500,000 damage every 10 years. The commission concluded that the values at stake in this watershed justify the expenditure of $93,000,000 on channel improvements. The New England flood of the fall of 1927 took 88 lives and caused

damage of $30,000,000 in Vermont alone. The board of engineers studying the Vermont flood situation reported that it would cost at least $40,000,000 to prevent, by means of storage reservoirs, a repetition of the 1927 disaster.

### FORESTS AND THE WATERSHEDS

Considering the importance to the northeastern States of their municipal water supplies, their water power, and their navigation, and the damages which they suffer periodically from floods and at all times from erosion, the condition of their watersheds with respect to control of run-off is obviously a matter of the greatest concern. The vegetative cover on these watersheds is the one factor in this condition which it appears to be within human power to control.

#### LOCATION OF THE FORESTS WITH RESPECT TO CRITICAL AREAS

Practically the entire region was once densely wooded. Some kind of forest still covers 54 percent of it. The forests are in general located on the steeper slopes at the headwaters of the streams, where there is every reason to believe that a cover of protective vegetation is most badly needed. Forests are, however, nearly absent from a few streams which flow for almost their entire length through agricultural land and which are important as sources of municipal supply. On one of the most critical watersheds of the entire region, from the standpoint of floods, the percentage of forest is rather low: this is the Passaic River watershed, with little over 50 percent in forest.

#### ORIGINAL AND PRESENT CHARACTER OF FORESTS AS AFFECTING EROSION AND STREAMFLOW

The original forests of the northeast, now practically gone, were composed of spruce and fir in the north and at the higher elevations further south; northern hardwoods, white pine, and hemlock at intermediate elevations; and mixed hardwoods, largely oak, or hardwoods and hard pines, at the lower elevations. The early cuttings, except when followed by fire, probably did little real damage to the forest.

Even at the height of the lumber industry large continuous areas of forest were not often cut clean, and removal of the logs from the woods with animals generally in winter, injured the remaining trees and young growth very much less than have the logging methods of many other forest regions. Unfortunately, fires have followed cutting on a great many areas, so that there are in the region as a whole about 10 million acres of forest land not now satisfactorily stocked to valueable tree species. These areas include grey birch, scrub oak, aspen-pin cherry, and similar forest types nearly worthless commercially. Probably the most conspicuous and important change wrought by cutting fires in the original forests has been a reduction in the proportion of softwoods. A second important result has been the conversion of great areas of originally all-aged forests to an even-aged condition.

Cutting in the spruce woods for pulp and lumber has unquestionably resulted in an inferior growth, but not often in the total destruction of the cover. Over considerable areas the spruce and balsam

have been replaced by aspen, birch, and other hardwood species. Although probably not as effective as the conifers in building up a good vegetative cover and a heavy litter, these species are excellent soil binders. There are some areas where restocking, even with hardwoods, has not followed cutting and fire, and here and there in New England and New York are mountain tops which have been denuded of their very soil by severe fires and consequent erosion. On less thoroughly denuded areas the first cover to appear is scanty grass and herbs, followed by brush. The conversion to a good forest condition is extremely slow.

The white-pine forests have probably suffered more severely from cutting and fire than any other forest type in the region. When destroyed, the white pine often has difficulty in reestablishing itself in competition with inferior vegetation. Exposure of the soil during the slow return of the pine is less serious than it would be if the pine did not occur for the most part on sandy soil.

The northern hardwood forests are probably in better shape than any other forest type in the region. Fires are less prevalent than in the conifer or oak forests. Slash appears to decay more quickly after cutting, and the forest seems to be less inflammable at every stage of development. The hardwood leaf litter breaks down rapidly into humus. In the absence of fire, reproduction is excellent even following clean cutting. Repeated fires, or a single severe fire in slash, may reduce this type to aspen-pin cherry of no commercial value and too open to produce a deep leaf litter.

The oak forests have suffered from overcutting, fire, and the chestnut blight. A large portion of the oak type is today at least the third generation from the original forest, and because the second cutting generally took place before the trees had reached full seed-bearing size, the third growth is very largely sprouts. The blight has eliminated chestnut from the region, and although its place in most stands has been taken by other species, there are ridges and south slopes where a good forest cover has not yet developed. Where fires have been particularly frequent in this type, as in the anthracite-coal region of Pennsylvania, the forest has degenerated into scrub oak and grey birch thickets. The scrubby species are not only commercially worthless but render artificial rehabilitation—planting—of the site extremely difficult. In southern New Jersey the mixed oak and pine forests have been repeatedly cut for fuel wood on a short rotation. Because some of the hardwood stumps fail to sprout, and because periodic fires have tended to wipe out pine seedlings starting from windblown seed, the forest has become progressively more open and filled with underbrush.

### OWNERSHIP

The farm woodlands which constitute a considerable part of the forests of the region are generally in better shape than the larger tracts owned by forest industries. Some of the loblolly-pine woodlots of the Eastern Shore of Maryland are particularly productive.

Substantial areas in State ownership, notably in New York and Pennsylvania, have received better-than-average fire protection for a good many years, and have been subject to little or no cutting. Their growing stock has steadily built up. Locally, a long-continued ebb in forest industries has brought about a similar condition on lands

in all ownerships. It is probable that there is now more timber at or near merchantable size in northern New Jersey, for example, than at any time since the Civil War. Fire protection is unquestionably beginning to show its effects in most of the region.

Public ownership has been an unquestioned factor in the restoration of the forests of this region. Over 10 percent of the forest area is now publicly owned, and most States have an acquisition program of considerable magnitude. New York already possesses nearly 2½ million acres of forest land, and is actively buying another million. Pennsylvania has nearly 2 million acres in State forests and State game lands. Federal ownership in the White and Green Mountains of New England now covers more than half a million acres. These Federal forests have been established primarily because of their watershed value. It is particularly significant that many municipalities in this region own watershed forests. In every State communities have acquired part of the land from which they obtain water, and where these lands have required reforestation they have been planted. Some 350 communities in New York now possess municipal forests; New York City has the largest area on its Ashokan Reservoir drainage. Glens Falls has planted more than 2 million trees on the denuded land acquired as a city watershed. Cities and towns in Massachusetts own over 50,000 acres of watershed forests. Forty towns in Vermont possess municipal forests, largely for watershed protection. Newark, N.J., has a watershed forest of 35,000 acres. Private water companies own considerable acreage of forest land. Forests on municipal watersheds not only serve the local public by yielding good water, but they have returned revenues from the sale of forest products. Altogether in the region of northeastern drainages the public owns some 5½ million acres of forest, the greater part of which may be classed as protection forests.

## CONCLUSIONS

The abundant rainfall and the many streams of the northeastern United States are during the greater part of the time, and under most conditions, an enormous asset to the region. At other times, and under some conditions, they are a very great liability. Both as an asset and a liability they are of extreme importance.

Because rates of run-off and stream flow are immensely increased by steep slopes protection of watersheds is particularly necessary in the more mountainous portions of the Northeast. The zone, shown in figure 3, where the forests are believed to exert a major influence on watersheds, is prevailingly mountainous, and includes most of the land previously described as very steep or steep. The forests here should be classified as protection forests. The area of moderate influence coincides roughly with the moderately steep and part of the gently rolling land, and that of slight influence with the remainder of the gently rolling and practically all of the flat land. There are local exceptions to these classifications, but only the coastal sands subject to wind erosion are large enough to map. The forest on the latter is today either in very bad shape or entirely lacking, but it or some other form of soil-binding vegetation is clearly needed. It should be noted that the relatively level watersheds from which many large municipalities in the region derive their domestic and industrial water have not been included in the area of major forest influence, although their

inclusion might be justified by the critical importance of water in this zone of dense population. The low percentage of forest land, however, makes it difficult to justify such a classification in advance of evidence, drawn from local experimentation, on both the absolute influence and the relative influence of the forest as compared with very carefully managed agricultural crops.

Roughly, one third, or 14,000,000 acres, of the forest area of the region is included in each of the zones in which the forest is believed to exert a major, a moderate, and a slight influence on run-off and stream flow.

There is every reason to believe that whatever measures of protection and management promote other values of the northeastern forests will also increase their value as regulators of stream flow and preventives of erosion. They should be adopted forthwith. These measures, as described in other sections of this report, include (1) intensified fire protection wherever in the region recognized objectives of fire control have not yet been reached, (2) halting devastation of any land, public or private, and (3) improving watershed conditions by planting where necessary. Present knowledge leads to the belief that about a half million acres of major influence land in the northeastern drainages require planting for watershed purposes alone. If adequate fire protection and planting in certain localities—such as the anthracite coal region of Pennsylvania—involve expenditures so far beyond those which the private owner can afford to make that the public is forced to assume the greater part of the burden, outright public acquisition appears inescapable. Intensified fire protection and halting of devastation will go a long way toward protecting the existing forest cover against degeneration. The public need for water and for safety from floods and erosion suggests that some 7.8 millions acres should be publicly owned and managed. Approximately 900,000 acres of this total is abandoned farm land.

A third major need in the solution of the stream-flow and watershed problems of the region is research. There is need for exact experimental evidence on the relative water use of the different species of native vegetation under the climatic conditions peculiar to the region and under different geological conditions. Differences in interception of rainfall by the crowns, in rate of percolation and absorption through the leaf litter and in rate of snow melt beneath tree crowns, must be determined for various types and species. Control of drifting sands by vegetation should be studied. The effect upon run-off and stream flow of a mixed conifer and hardwood forest as compared with a pure forest of either conifers or hardwoods; the effect upon wind movement and evaporation of an all-aged forest as compared with an even-aged forest—these and similar problems arising out of intensive management may be solved only by experimentation. Research should be conducted first and on the most comprehensive scale in the zone of intensive use of water for domestic and industrial purposes.

## SOUTH ATLANTIC DRAINAGES

The South Atlantic drainages, as the term is here used, include the Potomac River and all of the streams draining into the Atlantic Ocean southward from it, to but not including the Savannah River (fig. 4). Because of the difficulty of segregating for different portions of a

State many of the State-wide statistics later quoted, this report will make little or no reference to Maryland, and treats South Carolina as a unit.

## CLIMATE AND PHYSIOGRAPHY

The region is one of abundant rainfall—40 to 50 inches annually at most points. A few valleys at the head of the Potomac River receive

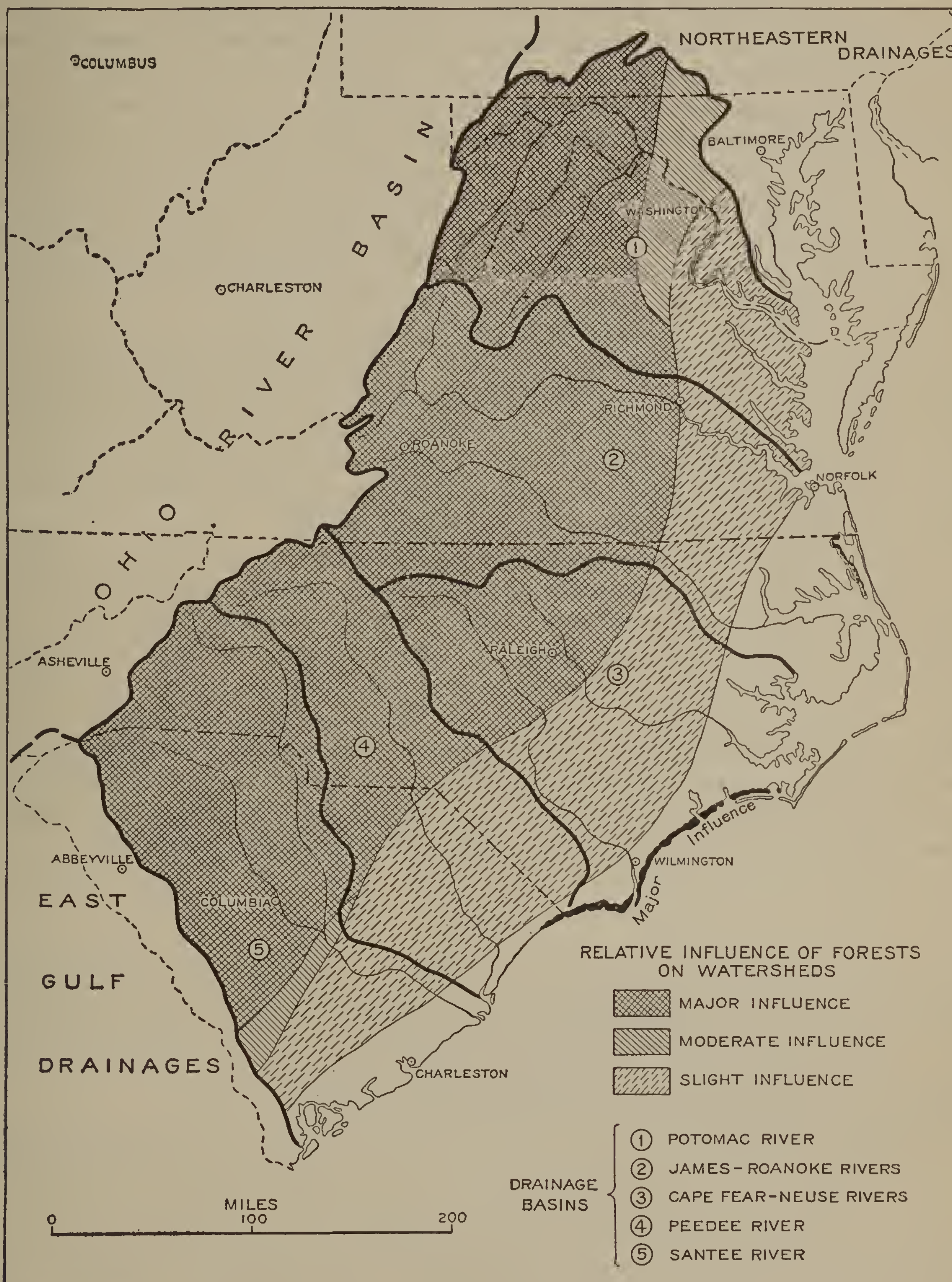


FIGURE 4.—South Atlantic drainages.

less than 35 inches of rainfall a year, and in South Carolina adjacent to the zone of highest precipitation in the eastern United States, the Blue Ridge receives an annual rainfall of 65 inches. Although there are no well-marked wet and dry seasons, rainfall is less equably distributed throughout the year than in the northeastern United

States. Midsummer precipitation, although high on the average, is irregular. At several places as much as 9 inches is recorded as having fallen in 24 hours, and at one point there is a record of 22 inches within 2 days.

Snowfall is generally unimportant, running from a yearly average of less than 5 inches along the seacoast of South Carolina to 30 or 40 inches on the upper Potomac watershed.

The region is divided into three distinct physiographic provinces: The coastal plain, the piedmont, and the Appalachian Mountains. The coastal plain rises from sea level to between 200 and 400 feet at the Fall Line, where it adjoins the piedmont. Considerably more than half of the coastal plain is flat, and below 100 feet in elevation, but with the rise in elevation westward the land becomes gently rolling, and breaks into rather sharp differences in elevation between the ridges and the stream bottoms. The piedmont plateau rises from the Fall Line to elevations of 600 to 1,500 feet; the general topography varies from gently rolling to somewhat broken.

From the western boundary of the piedmont plateau the mountain province rises, sometimes by as much as 2,000 feet in the space of 3 miles, to the summit of the Blue Ridge, which in the Carolinas is from 3,000 to over 4,000 feet above sea level. In the Virginias and Maryland the eastward flowing streams originate against ridges farther to the west, and flow in narrow gorges through the Blue Ridge which is here much lower in elevation than farther south.

The soils of the coastal plain are predominantly sandy, but there is considerable diversity as between the nearly pure sands of the Sand Hills, and the loams and even silt loams of other localities. The piedmont soils are predominantly deep clays, with some sandy loams, clay loams, and silts, which are particularly subject to erosion. The mountain soil types merge with those of the piedmont on the slopes of the Blue Ridge. Although on the whole remarkably deep for mountain soils, they are shallower, of lighter texture, and more stony than the piedmont soils. West of the Blue Ridge in Virginia many soils are derived from limestone and calcareous shales.

## EROSION

Erosion, involving both deterioration of soil and the silting of reservoirs and navigable channels, is the overwhelmingly important watershed problem of the South Atlantic drainages, and one which has reached very serious proportions on the piedmont plateau and in adjacent portions of the other physiographic provinces.

The clays, clay loams, and silts which characterize the piedmont are subject to erosion wherever exposed by clearing or by lumbering and fire. They are particularly subject to erosion when loosened by plowing, and, as has already been stated, when robbed of organic material by long-continued cultivation or repeated forest fires. Silt lands erode even more readily than the compact clays. Surface run-off in time cuts tremendous winding gullies through such soils.

The piedmont soils probably erode more rapidly under even the most skilful cultivation than if the native vegetation had remained undisturbed. Unfortunately great areas of these soils have been handled with little skill. Thousands of fields in the piedmont have been plowed up and down hill instead of along the contours, or in

terraces; cash crops—corn, cotton, and tobacco—have been grown under clean tillage; and the organic content of the soil has been steadily depleted. Tenancy has increased, in many counties up to 80 percent, and the irresponsible attitude of the typical tenant farmer has accentuated these tendencies. Whitney, in his "Soils of the United States", says of tenancy: "It is a general experience that soils deteriorate under tenant farmers, who have little interest in the welfare of the farm beyond the year of certain occupation and little capital and insufficient stock to work with."

Fairfield County, in the Santee River drainage of South Carolina, is an example of the erosion situation in the piedmont. The soil survey of this county in 1912 showed that 90,000 acres of land, largely cultivated at one time, had been permanently ruined by erosion. The whole area has been dissected by gullies, and bedrock is exposed in thousands of places. The State Forester estimates that in each of the adjoining counties from 10,000 to 30,000 acres have been similarly injured. W. W. Ashe computed in 1908 that an average of more than 850 pounds of soil per acre were yearly washed from the watershed of the Yadkin River above Salisbury, N.C. Of this more than125 pounds was humus, chiefly from farming soils, and the balance mineral soil.

Erosion from cleared lands, continues at least for a period, when the lands pass out of agricultural use. If the abandonment is permanent, they become potential forest land, and their erosion is the forester's problem. In the past two decades there has been a general decline in rural population and an increase in land abandonment.

Opinions differ as to how rapidly abandoned farm lands in the piedmont will revert to forest or other volunteer cover, and thereby be preserved against further serious erosion. The county demonstration agent of Fairfield County, S.C., believes that 75 percent of the gullied land in this county will restock naturally within 3 to 5 years. On the other hand, the extension forester of North Carolina, who estimates that for his State as a whole there are approximately 2 million acres of idle and submarginal cleared lands which should be returned to forest, believes that only 50 percent of this will restock naturally within 10 years. The other 50 percent, he asserts, will require definite planting, and 25 percent, or 500,000 acres, will require some mechanical assistance such as soil saving and brush dams, plowing in of gullies, etc.

Unquestionably such differences of opinion arise out of variations in the condition throughout the very large territory involved. The light-seeded loblolly and shortleaf pines characteristic of the region are difficult to keep out of cleared land adjacent to mature stands, but a few scattered trees along fence rows across large cleared areas cannot be counted upon to seed the land promptly and effectively after abandonment for cultivation.

Poorly farmed land and abandoned farm land are the chief sufferers from erosion on the piedmont plateau. A third class of land which is subject to some degree of erosion is heavily cut and repeatedly burned forest. Abused forest land is important because even on the piedmont a considerable percentage of the land is in woods; only two counties out of all those in the region have less than 20 percent of their area in forest and only 24 show less than 40 percent of forest cover. Leaf litter from several years' fall accumulates on forested ground. A

single fire may remove this entire protective mantle. Heavy cutting of the forest prevents its prompt replacement. Because hardwood leaf litter blows from place to place, and may thereby be absent from considerable areas, any cutting in mixed stands of pine and hardwoods that reduces the proportion of pine encourages erosion.

In the mountain province, in spite of heavy and often concentrated precipitation and abuse of the forest by fire and cutting, the streams from forested watersheds run extraordinarily clear. However, the soils of the mountain area are easily eroded when exposed. Land clearing for agricultural purposes, although of minor importance as far as area is concerned, is a major factor in erosion. Indeed, so rapidly does erosion take place that many fields are eroded and abandoned before the girdled trees have fallen. Geologists, foresters, and agriculturists alike agree in ascribing most of the erosion in the mountains to land clearing and to agriculture on steep slopes.

Investigations by the Geological Survey [32] in the southern Applachian region have shown that erosion takes place almost universally on cleared slopes. Glenn estimates that slopes in excess of 15 percent should not be cleared although as he points out, some slopes of 10 percent erode faster than those of 30 percent. What the safe gradient should be in any case depends upon the erosive characteristics of the soil. The soil of some fields is so impoverished by erosion that vegetation is unable to obtain a foothold and gullies continue to erode actively long after the abandonment has taken place. In places, the deeper gullies even eat back into the forest before the erosion is finally checked.

Measurements were made by the Appalachian Forest Experiment Station of the dry weight of suspended matter found in streams of western North Carolina following heavy rains in August, 1928. These showed that as the percentage of cultivated area in the drainage increased, a progressive increase occurred in the amount of silt carried by the stream. This ranged from 4,370 parts per million on a watershed from 85 to 90 percent in cultivation to 11 parts on a watershed where only 5 or 10 percent of the area was cleared. The material obtained from the agricultural watersheds was fine sand, clay, and silt; from the forested watersheds, mostly organic matter.

Grazing, although not important as a whole, is locally a cause of serious erosion. Too intensive grazing use and pasturage of steep slopes have been responsible for deep gullying. On some of the "balds," cattle trails have resulted in erosion which, spreading rapidly in the shallow soil, has exposed large areas of rock.

Timber cutting is often of little consequence as a source of erosion because new growth returns to the land quickly. Cutting, however, is often followed by slash fires which result in understocked stands and in these, erosion often continues for many years. In many cases, the dragging of logs down mountain slopes starts small gullies, but these are usually soon healed over.

Erosion is not a great problem in most parts of the coastal plain. Large areas near the coast are so close to tide level that exceptionally heavy precipitation, or overflow from the streams, remain on the surface of the ground for considerable periods before finally draining away. At higher elevations percolation of rainfall into the sandier

[32] Glenn, L. C. Denudation and Erosion in the Southern Appalachian Region. U.S.Geol.Sur.Prof Paper 72. 1911.

soils is very rapid. It is only where a loamy condition is approached that there is appreciable sheet erosion even from cultivated soils.

The relation of forest cover to erosion and other watershed and stream flow problems in the South Atlantic drainages is diagramatically shown in figure 4. In the mountains steep slopes and relatively heavy rainfall combine to make a permanent vegetative cover necessary if erosion is to be minimized. Forests still cover a high percentage of the mountains, and clearly exert a major influence on erosion. A considerably smaller proportion of land remains forested on the piedmont, in the mountain valleys of Virginia, and on the coastal plain adjoining the piedmont, where topography is only moderately broken and slopes are relatively short. In spite of this fact the absolute area of forest is so large, and erosion of the cleared land is so general, that here also the forest is considered to exert a major influence. The forests of the mountains, the piedmont plateau, and a strip of the coastal plain bordering the plateau may properly be classified as protection forest. In the greater part of the coastal plain, however, low relief would render serious erosion unlikely even in the absence of forests.

Wind erosion is common along the seacoast, where sand dunes occur. The drifting sand is held in place in some localities by a cover of pine and brush species, but elsewhere marches upon roads and other improvements, and in some places fills dredged channels. Fixation of drifting sand is a problem of some importance at points along several hundred miles of coast in Virginia and the Carolinas.

### WATER POWER

Water power is an extremely important and valuable natural resource in the South Atlantic drainages. According to the United States Geological Survey, North Carolina ranked third among all States in the Union in 1929 in generation of power from streams, and South Carolina ranked sixth.

Water storage on a large scale is highly desirable in producing power in this region, because of the extreme fluctuations in stream flow. The maximum flow of the major streams is here from 150 to 400 times the minimum flow; this contrasts with a ratio of 100 to 1 in the case of the Kennebec River in Maine. In order to maintain a steady flow for the generation of water power, artificial reservoirs have been created. The reservoir at Dreher Shoals, on the Saluda River in South Carolina, has a storage capacity of 524 billion gallons, which is said to be the largest capacity of any reservoir constructed for power, flood control, or water supply in the United States.

Control of silting is a grave problem in the management of storage reservoirs throughout the region. The Whitney Dam, above Badin, N.C., on the Yadkin River, was a 38-foot dam constructed in 1910. In 15 years silt filled the reservoir within a few feet of the top of the dam. Another example of a reservoir completely filled with silt from erosion is the Parr Shoals Reservoir in Saluda County, S.C.

### NAVIGATION

Maintenance of navigable channels in streams and harbors, in the face of continuous deposition of enormous quantities of solid matter—the product of erosion, is the third major stream-flow problem of

the region. According to the Chief of Engineers of the United States Army, about 7,860,000 short tons of freight were carried on the 14 principal rivers of the South Atlantic drainages in 1928.

The 1932 report of the Chief of Engineers shows that enormous sums have been spent by the War Department during the past 50 years in the improvement, chiefly by dredging, of these navigable waterways and harbors. Existing improvement projects have cost about $33,000,000 in that period.

The total sum spent by the United States in the improvement and maintenance of channels in South Atlantic streams, since the founding of the Republic, would come to a much larger sum.

### FLOODS

As might be expected in a region where differences of 30 to 60 feet in the height of large streams may occur within a few months, floods are sometimes very destructive. They are generally the result of a succession of rains, rather than of a single very heavy storm. The Santee River drainage basin, a high proportion of which has been cleared, appears to suffer particularly heavy losses, although records are fragmentary. Near Spartanburg, a flood in June 1903 took over 50 lives, swept away 14 cotton mills, and caused a total property damage of over $3,500,000. Unofficial figures, furnished by the State forester from Weather Bureau sources, indicate that between 1913 and 1922 South Carolina suffered losses of $19,337,000—practically $2,000,000 a year. Among recent floods in the region as a whole those of 1928 and 1929 were the most severe, causing damages in the three States of over $9,000,000. Virginia has suffered much less than the Carolinas from high water.

Glenn has indicated the great change which has taken place in the behavior of the South Atlantic streams. In addition to increased silting, this change has included greater irregularity of flow, and more frequent and higher flood stages. He states that this change is "reasonably believed to be due to the denudation of steep mountain slopes and their consequent erosion." Most of the change in the behavior of the streams he places at about the period of 1885 to 1890 when there was a rather general revival of industrial activity after the slow recuperation from the Civil War depression.

### URBAN WATER SUPPLIES

A considerable number of municipalities in the region derive their water supply from surface streams. Among these are Richmond, Va.; Raleigh and Charlotte, N.C.; and Spartanburg and Columbia, S.C. Storage is necessary, and here also control of silting presents a problem. For example, the municipal reservoir built by Raleigh in 1914 has been reduced more than one third in capacity by silt from the cleared land which makes up a portion of its watershed. A reservoir built in 1923, the watershed of which is wooded, has been silted very slightly.

### PERCENTAGE FORESTED

About two thirds of the total acreage of the region is in forest cover—probably a higher percentage than in the earlier period when

land clearing was at its height. The forest is remarkably evenly distributed. The proportion varies from 50 to 75 percent as between the larger drainages. A considerably higher percentage of the mountain and the coastal plain provinces is forested than of the piedmont province, but, as already stated, only 24 counties in the region show less than 40 percent forest cover, and only 2 less than 20 percent.

### ORIGINAL AND PRESENT CHARACTER OF FOREST AS INFLUENCING EROSION AND STREAM FLOW

Comparatively little of the virgin timber of the region now remains. A large area has been cleared for agriculture. Some of it went back to forest during the Civil War, and some has again been cleared. On the piedmont farm woods are typically interspersed with agricultural land. But on the poorer sandy lands and alluvial bottom lands of the coastal plain, and in the rougher portions of the mountains there are extensive and continuous forests.

In the mountains, about 70 percent of the area is in forest. This is largely a mixture of oaks, hickories, tulip poplar, ash, maple, beech, basswood, chestnut, and a large number of other species. Repeated culling of the better quality woods has converted much of the original high-grade forest into an inferior one. Fire has resulted in further depletion of the culled stands, until now the forest in many places is for the present almost worthless commercially. The most obvious effect of fires on watershed protective values is the destruction of leaf litter. Litter under a good forest cover in the mountains accumulates to a depth of several inches; its dry weight, in one study made by the Appalachian Forest Experiment Station, was found to be as much as 13,000 pounds an acre. Other studies by the station show that it may absorb up to four and one half times its own weight of moisture. This retention of water by litter may itself be important in lessening run-off from heavy storms, but its effect has been shown by experiments in this region and elsewhere to be completely overshadowed in value by the favorable effect of litter upon absorption of water into the soil below. When litter is destroyed, as by fire, the soil soon becomes less porous, and less able to store large quantities of water. Fire protection in the mountain region is variable. In some places, as on the national forests, fire losses have been kept to a reasonably satisfactory figure. State and county effort has developed well in part of the region. Private efforts at protection of the forest against fire are sporadic.

The forests of the piedmont are characteristically a mixture of hardwoods and pines. Pure hardwood stands are common, as are pure stands of shortleaf and Virginia pines at the north, and of shortleaf and loblolly at the south. In places a mixed hardwood forest is found. The farm woodlands, being isolated, have suffered less from fires than have the large continuous areas of forest land in the mountains, and the cutting methods applied to them have probably been less destructive than those employed elsewhere. Grazing, which is permitted in many farm woodlands, is a severe handicap to young growth.

On the coastal plain, from Virginia south, the original upland forest was dominated by longleaf pine, although on the more compact clays and silts loblolly pine, and in South Carolina slash pine took its place.

Hardwoods, such as oaks and gums, formed an important part of the forest. Along the rivers and in the coastal swamps a mixed forest occurred, but cypress and southern white cedar were also of great importance. The forests of the coastal plain have been cut very heavily. Longleaf pine has been practically exterminated from Virginia, and in North Carolina it has been very largely replaced by loblolly pine. Fires have been particularly frequent and widespread in the coastal plain, and would have devastated wide areas had not the indigenous species of pine, particularly longleaf, been relatively resistant. In Virginia and the Carolinas as a whole an average of 366,000 acres of land under protection burned yearly between 1926 and 1930. Of the millions of acres not protected in the region, it was estimated that in 1931 about one quarter burned over. Statistics for the coastal plain separately are lacking, but it is probable that the bulk of the fires occurred in this physiographic province.

By far the greater area of forest lands in the South Atlantic drainages are in private ownership, and the present impoverished condition of the watershed cover is a reflection of private land management. Some national forest lands purchased in the mountain area are in decided contrast to the private lands because in the past 20 years they have received incomparably better fire protection, the cutting has been done in such way as to encourage regrowth, and the badly eroded agricultural lands have largely reforested. Although a full cover has not yet developed in the short time these lands have been administered, watershed conditions have steadily improved. Private lands, however, still evidence the lack of adequate protection and management. Conditions on State and other local public lands, with some notable exceptions, resemble more those on the privately owned land than they do those on the national forests.

## CONCLUSIONS

That a permanent vegetative cover on a watershed is a powerful preventive of erosion is clearly shown in the South Atlantic drainages by the relative clarity, even in flood, of streams flowing from land in forest or permanent sod, as compared with the turbidity and heavy silt load characteristic of streams flowing from cultivated land. Although there has not been enough experimentation in this region to furnish conclusive evidence that forests exert other favorable influences on streamflow, research elsewhere in the United States, even though with other forest types, climates, and soils, tends to the belief that they do. The magnitude and gravity of the erosion and streamflow problems of the South Atlantic drainages certainly warrant the following conclusions: (1) That where forests already exist in the region they should be protected against fires, destructive lumbering, and other treatment likely to impair their favorable influence on erosion and streamflow, and (2) that where erosion of land now cleared has forced, or is forcing, its abandonment for agriculture, its prompt reforestation and administration as a permanent protection forest are necessary.

First-class fire protection is justified from every point of view—either that of reaping a full crop of wood under a climate favorable to rapid growth, or of realizing the full indirect benefits of a forest cover. A very small percentage of the region is now receiving first class fire protection. After 18 years' effort Virginia does not even attempt to

protect more than 63 percent of her forest area, and after 18 years North Carolina does not attempt to protect more than 39 percent. In South Carolina only the barest start has yet been made toward fire protection. Even within the protected areas the percentage of burn in 1931 ranged from 1.4 in Virginia to 7.7 in South Carolina. The standards set up in the section "Protection Against Fire" should by all means be put into effect in the region, through the combined efforts of the public and the landowners.

Such simple restrictions upon cutting and grazing as are necessary to prevent devastation of forest land (see the section "How to Stop Forest Devastation"), and control of epidemic insects and diseases, are obligations of ownership, and may be expected to contribute to the beneficial influence of the South Atlantic forests on erosion and streamflow.

Restrictions are also necessary upon clearing of steep slopes because such clearing is a very fruitful source of erosion and heavy surface run-off.

Again, as in the Northeast, there is a very great need for substantial research into the relationship of forests and waters, including water use by different species of trees and other natural vegetation; interception of rainfall by crowns; capacity of leaf litter to absorb and to filter precipitation; nature and condition of the organic layers of the soil in relation to percolation and run-off; effect upon wind movement and evaporation of pure versus mixed forest, and of even-aged versus all-aged stands; and control of drifting sands by tree growth.

The most critical watershed and streamflow problem of the South Atlantic drainages, however, is not that of land now in forest, but of cleared land which has been abandoned for agricultural use, or which, under present methods of farm management, is certain to erode until so abandoned. The Bureau of Agricultural Economics estimates the present area of abandoned farm land available for forestry in Virginia and the Carolinas at slightly more than 5 million acres. Although no direct evidence is available on the point, it is probable that approximately two thirds of this area, or roughly 3.3 million acres, is eroding seriously. In so far as improved farm management can save eroding lands still in agricultural use from further deterioration, and can point the way to their continued use at a profit, the erosion problem is not one for the forester. But if abandonment of agricultural land continues here at the rate predicted by the Bureau for the nation as a whole, by 1950 over 2½ million acres—probably half of it eroded—will be added to the present abandoned acreage, and reforestation will be the only alternative to completely ignoring the erosion menace.

Prompt reforestation of these abandoned farm lands is necessary to meet the menace. If the estimate of the local foresters that a large part of eroded farm land will reforest naturally within 10 years of abandonment are applied to the region, planting will have to be done on about 2 million acres. It also seems probable that of this huge area of abandoned farm lands, about 1 million acres will require preliminary treatment, such as plowing in of gullies and building dams. It is very difficult to see how the landowner can be persuaded to undertake such work on any adequate scale. It is entirely out of the question to interest a tenant in it.

Public acquisition and management of 3.3 million acres of abandoned lands or of such submarginal farm lands clearly headed for abandonment, none of which will reforest naturally within a decade, appears to be the only prompt and effective solution of the erosion problem on much of the piedmont plateau, in adjacent portions of the coastal plain, and in the mountains. Wherever the areas to be acquired are scattered, or difficult to administer because of small size, local handling—preferably by counties—is naturally suggested. But it is very doubtful whether counties that have suffered a continuous shrinkage in their area of improved farm land, and even the States themselves that have not yet financed State-wide fire protection, can handle a purchase, planting, and engineering investment covering hundreds of thousands of acres. Even if tax-title were obtainable, there would still remain the planting and other items, and subsequent annual costs of protection and administration. Heavy Federal participation seems inevitable. It is certainly logical for the Federal Government, which has spent $33,000,000 on dredging and other maintenance of navigable streams within the States comprising the South Atlantic drainages, to spend a few million dollars additional to safeguard its investment.

Similarly, the large area of mismanaged and inadequately protected forest land in the mountains and in the piedmont should also be in the hands of the public. Administration of a type similar to that given the national forests would meet the watershed situation and restore the streams to their pristine condition. All of the forest area of major influence, some 15½ million acres, should be in public ownership. Whether these lands, like the abandoned agricultural lands, should become national forest, or county and State forest through some form of Federal cooperation, is a detail to be worked out when all the facts have been more carefully ascertained than at present.

## EAST GULF DRAINAGES

The East Gulf drainages as here discussed include those portions of the Southern States drained by the rivers from the Savannah to the Mississippi. As shown in the accompanying map, figure 5, there are seven of these rivers. The map shows the areas on which according to our present knowledge a forest cover exerts or should exert a favorable influence upon stream flow and erosion, and in a general way indicates the relative degree of this influence. The forest areas of the drainages are classified according to watershed protective influence as follows:

| | Acres |
|---|---|
| Major influence | 18, 709, 000 |
| Moderate influence | 4, 335, 000 |
| Slight influence | 50, 269, 000 |

The southern portion of Florida, which is not shown on the map, and the portion of south Georgia that drains into the Okefenokee Swamp present no watershed protection problem. They are very flat and very near tidewater level. Much of the excess water from torrential rains collects in swamps and runs off slowly. The soils are mostly absorptive sands, and comparatively little erosion takes place on the cultivated lands.

In Florida the more inland dunes, as on the Chocatawhatchee and Ocala National Forests, have become stabilized under a forest or

brush cover. Some of the coastal dunes are in motion because of distrubance to the cover or of the inability of vegetation to become established. Occasionally dune movement threatens roads or other improvements, but for the most part, the moving dunes do little damage.

## FACTORS IN STREAM FLOW AND EROSION

### PRECIPITATION

The East Gulf States receive about 55 inches of rainfall annually. Rains occur throughout the year. Heavy torrential rains are common close to the Gulf and also, to a lesser degree, in the interior.

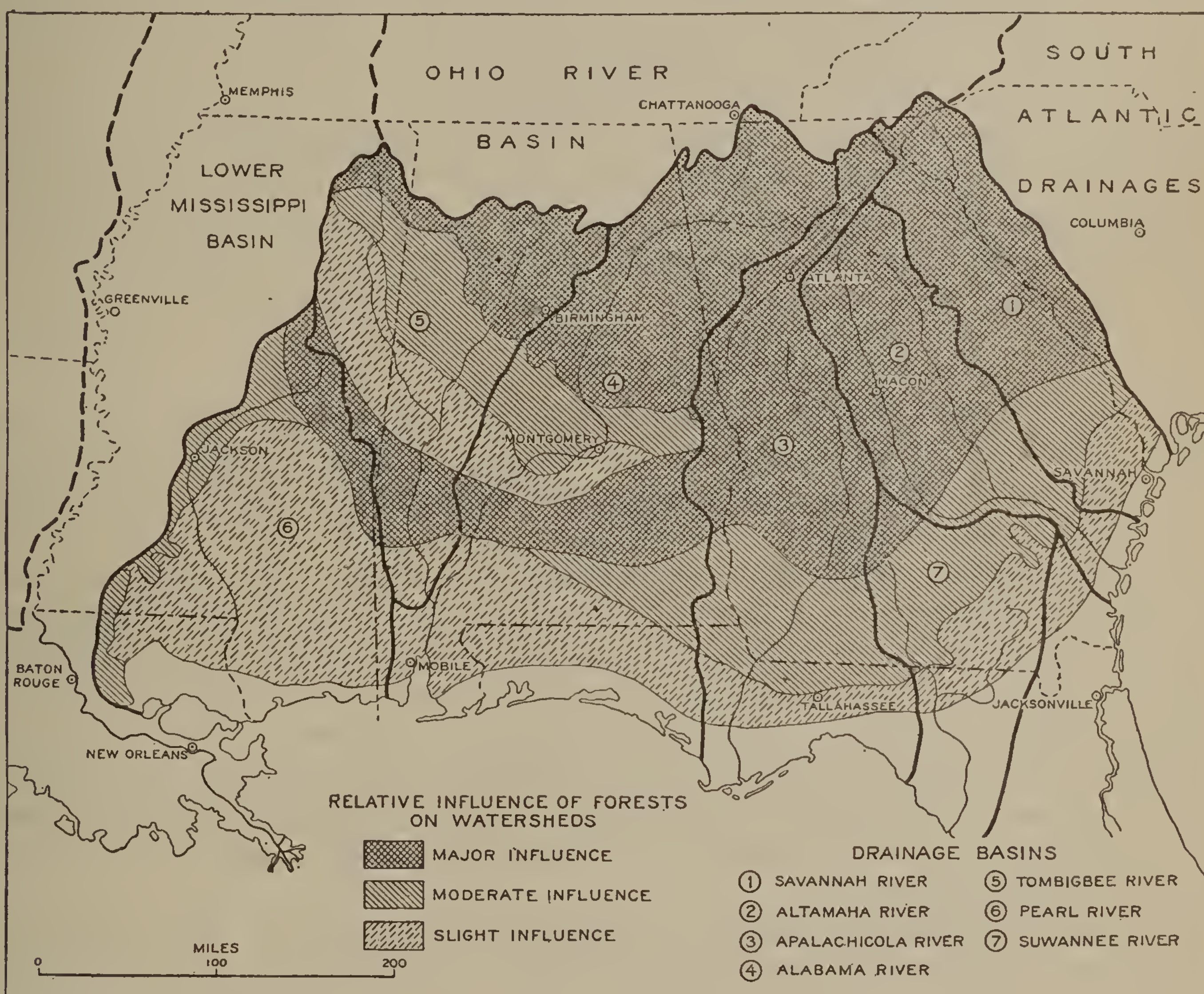


FIGURE 5.—East Gulf drainages.

Weather Bureau precipitation records for the Alabama River drainage show a wide variation in the quantity of rainfall that occurs in individual storms. In one instance in the basin of the Coosa River, a major tributary in central Alabama, the rainfall ranged from 8 to 20 inches.

Rainfall exceeding 2 inches in 24 hours is not uncommon; indeed, summer rains of more than 5 inches in a 12-hour period have been recorded. Storms of such intensity, particularly if the soil happens to contain much moisture at the time, result in major floods and widespread erosion. Some storms cover a relatively narrow belt, others are widespread. Some storms, principally in the fall, originate as tropical hurricanes. Most of the rains causing severe floods come in the winter or spring.

### TOPOGRAPHY

The East Gulf area may be divided into three physiographic provinces; the coastal plain, the piedmont, and the Appalachian highlands. The Coastal Plain rises from sea level to between 200 and 400 feet, where it adjoins the piedmont. Much of the Coastal Plain area is flat and less than 100 feet in elevation. Inland the elevation increases more rapidly, the land becomes more rolling, and occasionally sharp differences in elevation occur. The piedmont rises to elevations of 600 to 1,200 feet, the topography varying from rolling to broken. Most of the hills are broad and of such even slope that agriculture early claimed a large part of the hill land. The Appalachian highlands rise to a maximum elevation of about 4,000 feet in northern Georgia, at the southern end of the Appalachian Mountains. Rough topography is characteristic of much of the highland area.

It is largely because of steep slopes and rapid run-off from bared soils that a very large part of the highland forest is classed as having a major influence on watershed conditions. It is largely because of poor drainage due to insufficiency of relief that the Coastal Plain forest is classed as having little influence upon watershed conditions.

### SOILS

In the Coastal Plain, absorptive sands are the predominate soil type. These are comparatively shallow on some areas where hardpan has developed. On the upper Coastal Plain the sandy soils give way to highly erosible loams.

The piedmont soils are predominantly deep clays, which erode rapidly when exposed. Cultivation greatly hastens erosion. Although the piedmont subsoils unlike most others, can be cultivated if fertilized, yet here as elsewhere the subsoils are much inferior to surface soils in both absorptive and water-holding capacity. Consequently, exposure of subsoils over large areas increases floods and renders stabilization of streamflow difficult. It is largely because of their easily eroded soils that the forests of the piedmont are classed as having a major influence.

The soils of the highlands are inclined to be stony. Some are clay soils derived from limestone and shales, others are loam. Save for occasional pockets of deep loam and for rare areas unburned by recurrent fires, the highland soils are much shallower and poorer than those of the piedmont. For this reason they do not absorb and hold as much water as the piedmont soils. The fact that they are shallow makes it all the more necessary to maintain the cover upon them intact.

### FOREST CONDITIONS

In the highland section, hardwoods predominate. At less pronounced elevations pines, particularly shortleaf, occur with the hardwoods. This mixed forest has been repeatedly culled of its best timber. In places it has been severely cut and repeatedly burned, with the result that it has been converted into a more or less open and scrubby woodland. On approximately 20 percent of the forest land in the highlands the forest stands have been either destroyed or badly culled and burned. Much of this land is pastured, and this form of use intensifies the deterioration of the remaining forest.

Many slopes in the highlands have been cleared and put into crops. Observations indicate that on slopes steeper than about 15 percent agricultural use leads to gullying so severe that the land is quickly abandoned.

Privately-owned forest lands in the highland section burn frequently. Hardwood sprouts and other vegetation come in on some areas denuded by fire, but because of fire many cut-over lands have failed to restock quickly and are without adequate litter and humus. On public forest areas such as the Cherokee and Alabama National Forests, litter and humus have developed under fire protection. These national forests were established at the headwaters of the Apalachicola and Black Warrior Rivers because of the influence of the areas on stream flow and erosion. That this influence is decidedly beneficial is shown by the fact that the streams from the national-forest areas, formerly muddy, now usually run clear.

In the Piedmont and Coastal Plain sections, where pines predominate, fires are much more common. In the piedmont section, where much of the forest area is on farms, pasturing and fires go together.

Most of the upland pine forest is second growth. In logging pine stands it is customary to cut fairly clean, but usually a sufficient seed supply has been available to insure reforestation if fires are not too destructive. This is evidenced by the fact that although severe cutting and repeated burning have occurred extensively on the pine lands, only about 5 percent of these lands have been devastated. Fires kill small loblolly seedlings; shortleaf has the faculty of sprouting after being burned. Both pines are resistant to light ground fire after they have reached a diameter of a few inches.

Longleaf is the predominating tree of the Coastal Plain forest. Usually, before the mature pine forest is cut all trees large enough to support a turpentine face are worked for naval stores. Frequent fires before the naval stores operation and annual fires during it destory much advance growth. In logging, the trees large enough for the saw are cut first, then the larger trees that have survived the subsequent fires are taken for poles and piling. In some localities, logging followed by fire leaves the land completely devastated. On some areas, conversion from forest to grassland has taken place within a very few years. Only the remarkable persistence of longleaf seedlings in the face of repeated fire and the ability of the saplings to survive defoliation prevent this species from being almost wholly destroyed. As it is, something like 10 percent of the longleaf area has been devastated. If given a chance, however, the longleaf with the help of other species such as slash and loblolly reclaims some of the denuded areas. Clear cutting is less usual with second-growth stands, but they are heavily worked for turpentine and are subjected to frequent fires.

In the more moist parts of the lower Coastal Plain slash pine occurs with the longleaf. Practically all this is second growth. The slash pine is much more susceptible to fires in early youth than the longleaf, and escapes only because of its ability to grow in moist locations. During drouth, fires in these locations play havoc with the pine stands.

Cutting in the southern forests need not be destructive. In some places greater care in logging may be required than in others; on the whole, it should not be difficult to utilize both the timber and the

forage and yet maintain satisfactory watershed conditions. Control of fire, often set purposely, is far more necessary than any great change in cutting methods. Adoption by landowners of the standards set up in the section of this report entitled "Protection Against Fire" would satisfactorily meet watershed protection needs on private forest lands.

In Georgia, Florida, Alabama, and Mississippi, good fire-control organizations have been developed in some localities but only 20 percent of the forest area is protected. Until better fire control can be provided or until local woods-burning practices change, it will be impossible to get adequate protection. In 1929 and 1930 about 29 million acres, or 40 percent, of the total forest area not now protected (about 71 million acres) burned over each year. Where fires annually cover large areas of forest land, not even a scanty litter cover can develop.

Probably the largest fire-control effort of a single landholder is that of the Great Southern Lumber Co., in southeastern Louisiana. This company has succeeded in protecting its lands from fire largely because it has bought many of the small intermingled holdings and put considerable forest acreage under a tight fence. The latter has not only interfered with trespass and eliminated grazing fires but also excluded the hogs which destroy young longleaf seedlings.

Cattle grazing on forest areas is widespread, especially in the pine regions, but probably does little if any damage to the watersheds. Only locally, and usually only on farms, does overgrazing of consequence occur.

Forest conditions such as those described do not tend to regulate stream flow or to prevent erosion. The open forest does not develop a full litter cover even if unburned, and grass often occupies the space between the trees. As indicated in the introduction to this section, grassland has a higher surface run-off rate than forest. Thus a reduction in the density of the forest tends to increase flood heights.

How far a change from good forest cover to scrub or sprout forest cover affects surface run-off and erosion in this region is unknown. Data taken by the Southern Forest Experiment Station in the silt loam uplands of northern Mississippi show that a scrub forest helps to retard surface run-off in times of heavy rain. A dense scrub or sprout forest can probably prevent erosion, but all too often the sprout stand to which cutting and fire convert a high forest is an understocked stand. Such a forest certainly burns more frequently than the forest it succeeds.

## STREAM FLOW

The streams coming from the Blue Ridge highlands have a greater annual run-off than any other streams of the East Gulf drainages, the discharge being approximately equivalent to 30 inches of precipitation over their watersheds. Those from the piedmont and the coastal plain have a run-off equivalent to a precipitation of 20 to 25 inches. Fluctuation in flow is much less for the highland streams than for those of the piedmont and coastal plain; their ratio of minimum to maximum flow is about 1 to 100, whereas the Tallapoosa, for example, fluctuates from 65 to 102,000 second-feet, a minimum to maximum ratio of 1 to 1,569. The Army Engineers report that "in common with all rivers rising in the Appalachian Mountains, the (Apalachicola River) system exhibits a wide periodic fluctuation in volume of flow.

During dry periods the flow at the headwaters is well sustained through ground storage. The effect of low water is severely felt in that portion of the drainage area lying in the piedmont upland and the upper portions of the coastal plain." This undoubtedly is a reflection of forest conditions, since the forest occupies perhaps 60 percent of the total area in the highland section as contrasted with about 30 percent in the piedmont. It is more than coincidence that most of the power development is in the section where the largest area of forest is located.

At one time all the major East Gulf drainage streams were much used for navigation. Prior to the time of the railroads the head of navigation for the Apalachicola River was Columbus, Ga., 276 miles upstream. The upper stretches of the Apalachicola are no longer navigable except for the very lightest craft. On the Chattahoochee considerable sums have been spent by the Army Engineers in recent years to maintain an open channel of 4 feet. The report of the Inland Waterways Commission (1908) says of the Pearl: "This river has completely changed its character in the past 50 years; from a slow, clear stream it has become a swift, muddy one and from a good channel with a depth of 5 or 6 feet, it is now shallow and much obstructed by logs and drifts." In the Pearl River the available low draft for the lower 104 miles has decreased since 1875 to 2 feet, and in consequence all navigation-maintenance work by the Federal Government has been dropped. This change, which is common to all the East Gulf streams, reflects to a considerable degree the decrease in forest area and the degradation of the forest itself. It also reflects the decreased absorptive capacity of the soil brought about by agriculture and erosion.

Floods are not uncommon in this region. For their size they cause surprisingly slight property damage, largely because property values in the flooded areas are low and because the region is without a large urban population. Flood stages have been reached on the Chattahoochee River in 16 instances since 1900, and on the Tombigbee in 98 instances since 1903. On the average these high-water stages have lasted about 10 days each, but the most disastrous flood, in 1916, lasted 66 days. Nearly $100,000 was spent in aiding the victims of this flood. The average crop losses due to floods in the lowlands have been estimated at $3 per acre per year.

The floods of March 1929 caused damage estimated by the Weather Bureau to exceed $5,000,000 in the Choctawhatchee Basin, $1,000,000 in the Apalachicola, and $1,700,000 in the Alabama, in addition to heavy losses in other river basins. Cities such as Jackson, Miss., West Point, Ga., and Montgomery, Ala., have experienced serious inconvenience if not distress because high water entered the city water supplies, interfered with power and light service, or disrupted transportation systems.

## EROSION

Under the agricultural practices in effect in the piedmont and upper coastal plain, the top soil has been sluiced from thousands of acres of farm lands. As a result, a large area has lost its productivity. Some lands have been so gullied as to become worthless for agriculture. As in the South Atlantic drainages, a very large part of the agricultural land is being cultivated under a tenant system. In general this

system is characterized by indifference on the part of both the owner and the tenant toward the condition of the land. Census data show that in some counties negro tenants, many of them illiterate, are farming more than 80 percent of the crop lands.

According to H. H. Bennett, of the Bureau of Chemistry and Soils, much of the sloping land in the piedmont region on which pure stands of second-growth pine are growing is abandoned agricultural land from which the original soil was completely washed away. Mr. Bennett reports that in Spartanburg County, S. C., examination of the soil profile in remnants of the virgin forest of mixed hardwoods and pine showed the original soil to have consisted of about 4 to 8 inches of brownish or yellowish mellow sandy loam and loam. This top layer is gone or largely gone from 297,000 acres.

The loss of productivity on the eroded agricultural lands is reflected by census data. These show some 6½ million acres of farm land in the East Gulf drainages to have been abandoned in the past 20 years. Census data for Georgia show that the area of cultivated lands has decreased by 70 percent in Muscogee County, by 65 percent in Chattahoochee County, and by 51 percent in Hancock and Lincoln Counties. A reduction of almost 40 percent is shown for Coosa and Tallapoosa Counties, Ala., and similar reductions for counties in Mississippi. On many of the abandoned lands erosion is continuing.

In the report on a soil survey of Muscogee County, Ga., made in 1922 by the Federal Bureau of Soils in cooperation with the Georgia State College of Agriculture, it is stated that:

> Most of this soil type (Norfolk sand) was formerly cleared and farmed for a time because of its easy cultivation, but yields were small and erosion was so excessive that much of it was abandoned and allowed to grow up in pine and oaks. * * *. (The Norfolk sandy loam is) one of the most intensively farmed soils in the county * * *. The steeper eroded portions are allowed to remain in brush and pine.
>
> The construction of terraces on the slopes (Cecil soils) for the prevention of erosion and washing is now customary, and if this policy had been adopted when the land was first cleared many of the gullied fields that have since been turned out and allowed to grow up in pine and brush could be in use today * * *. Great care must be taken to prevent gullies from starting (in the Greenville clay loam), for they quickly destroy valuable fields if allowed to go unchecked. * * *. A large part of it (the Susquehanna clay) was originally cleared and considered excellent cotton soil, but erosion quickly made it of little value and it was abandoned. Most of it at present supports a growth of scrub oak and short-leaf pine.

The report on the soil survey of Stewart County, in western Georgia, made in 1903, states:

> A lower belt of broken country has been formed by the originally smooth upland being dissected by stream erosion. This belt is characterized by deep gullies, steep hills, and ridges with undulating crests. Some of the deeper gullies, locally called "caves", vary in width from a few feet to one fourth mile, and in depth from 50 feet to 100 feet or more. Their sides are precipitous or perpendicular. The roughest topography in this belt is south of Providence Church, where the surface is very broken, being probably the roughest section in the southern part of the State. In this section there is scarcely an area of land suitable for agriculture the size of an ordinary garden. Steep ridges rise to an elevation of 200 feet or more above the deeper stream bottoms. The country is so rough and broken as to lead some of the inhabitants of the county erroneously to believe that the hills are a southern extension of the Appalachian Mountains.
>
> The majority of the settlers occupied the clay hills, the level section of the county being avoided until a later day because of a belief that the land was of poor quality. Subsequently, the hill country became so badly gullied by erosion that this region was almost entirely abandoned. Many substantial buildings in

the vicinity of Louvale, Union, and Providence, abandoned many years ago, remain as an evidence of the early settlements. * * *. There is little possibility of this gullied land being restored to a condition favorable to cultivation. * * *. Except where some measure is taken to check the progress of the gullies, they extend with destructive effect at a rapid rate.

A watershed survey made in 1932 by the Southern Forest Experiment Station within the East Gulf drainages indicated widespread occurrence of erosion. In the piedmont section of the Altamaha River drainage 32 percent of the area was found to be eroded. In the central portion of the Apalachicola River Basin 24 percent of the area examined was found to be eroded. This was almost entirely crop land, pasture land, and abandoned farm land. In the Apalachicola drainage as a whole 15 percent of the piedmont and 12 percent of the coastal plain was found to be undergoing erosion. In the other basins similar conditions obtain. The total area of land on which erosion was markedly noticeable was estimated at about 1,000,000 acres in the Alabama River drainage, about 2,000,000 acres in the Apalachicola River Basin, and more than half a million acres in the Tombigbee River Basin.

Erosion on such a large scale results in deposits of soil where they are not wanted. The Dunlap Dam (Gainesville, Ga.), with a pond area of 350 acres, was completed in 1904. The drainage area is 483 square miles. In 26 years the reservoir was almost completely silted, the volume of silt deposit being estimated at 5,250 acre-feet, or 202 acre-feet a year. The original pond area of 700 acres behind the Morgan Falls Dam near Atlanta, also completed in 1904, has been completely silted. The silt deposit here is estimated at 16,800 acre-feet, or 646 acre-feet a year, for a watershed of 1,390 square miles. Some 35,000 acre-feet of silt in 18 years has been deposited behind the Goat Rock Dam at Columbus, Ga., from a drainage area of 4,530 square miles. The North Highlands Dam at Columbus and the New Bridge Dam on the Chestatee branch of the Chattahoochee have been silted to the limit. On the basis of silting studies carried on by Army engineers it is estimated that silting in reservoirs on the Chattahoochee River may be expected to progress at the rate of 45 acre-feet annually for each square mile of catchment area. Large deposits of eroded material have been deposited on flooded bottom lands, in some instances ruining fertile lands for further agricultural use. The Bureau of Chemistry and Soils reports some 9,000 acres of bottom lands in Stewart County, Ga., to have been thus ruined.

As erosion on agricultural lands proceeds, abandonment takes place. The control of erosion on abandoned land is in considerable part a forest problem. Deeply gullied lands, according to Bennett, probably cannot be reclaimed for crops without centuries of soil building. Much land in this condition will restock naturally to pines. Where the stiff clay subsoil has been exposed, however, it is at least questionable whether a stand sufficiently dense to control rapid runoff and erosion can develop without artificial aid and some special measures to control erosion. On probably one third and possibly one half of the lands needing planting, conditions are so critical that special erosion-control measures will be necessary if planting is to be successful and erosion is to be controlled. These will include check dams, the plowing of gullies, and perhaps even the use of sod to hold the soil in place until tree growth has become established. Certainly

planting of a large area is justified to halt erosion as quickly as possible, if for no other reason than to stop soil wastage.

Data are lacking as to the extent to which forest areas are eroded as contrasted with areas that have been in agriculture. The survey by the Southern Forest Experiment Station just referred to disclosed no forest areas where serious erosion existed. Undoubtedly some erosion occurs on forest areas, especially after fire and cutting, but in contrast with that on agricultural lands it is so slight as not to call for mention.

### SUMMARY AND CONCLUSIONS

The most critical watershed situation in the East Gulf drainages is in the piedmont and upper coastal plain, where mismanagement of agricultural lands has brought about widespread erosion and changed stream conditions. Abandonment of agricultural land is proceeding on a large scale. Although some of the abandoned lands will restock naturally with forest growth in a few years, it is estimated that about a million acres of watershed land needs artificial reforestation. Planting alone will not be enough; on probably one third and possibly one half of the lands needing planting, special erosion-control measures will be needed.

In the highland area, land clearing has resulted in so much erosion that it should not be permitted to continue on the steeper slopes.

On private forest lands, lack of management is reflected in understocking due largely to fire and cutting. Fire control probably would bring about better watershed conditions more quickly than any other possible measure.

Where cutting and pasturage practices have led to watershed deterioration they should be modified. If these practices cannot be changed on certain critical areas through education of the timberland owners and operators, these areas should be brought into public ownership. The present condition of unmanaged private lands in the highlands as contrasted with that of managed national-forest lands suggests that there should be a material expansion of the present public forest enterprise.

In the highland and piedmont sections, where erosion has reached a critical stage on some 4.6 million acres of abandoned agricultural land, there is need for some form of public control or for public ownership. The large area of forest land having a major influence on streamflow and erosion, 15.4 million acres, should be similarly handled. Only through good management can the streams whose regimen has been so seriously upset by man's activities, be restored to their former condition. Shrinkage of the tax base of the counties, and difficulties experienced by local governments in financing forestry enterprises and bringing about fire control, suggest that local political units can not go far by themselves.

Investigations are needed locally to determine how watershed conditions are affected by the forest cover, to what extent good conditions can be preserved through forestry practices and what special measures are needed.

## WEST GULF DRAINAGES

The watersheds of the West Gulf drainages comprise, in the aggregate, an area of approximately 124 million acres. The basin includes all of the streams in western Louisiana, and, with the exception of

the Rio Grande and Pecos Rivers, all the main drainages in Texas (fig. 6). The principal streams are the Sabine, Trinity, Brazos, and Colorado Rivers. The extreme variations in climate, soils, and vegetation throughout this extensive area have had a correspondingly profound effect on land utilization as well as on watershed conditions.

## CLIMATE IN RELATION TO WATERSHED PROBLEMS

Precipitation on these drainages comes almost entirely in the form of rainfall the rains varying tremendously in different portions of the basin. In the humid region of eastern Texas and western Louisiana the rainfall averages 50 to 60 inches annually as compared with

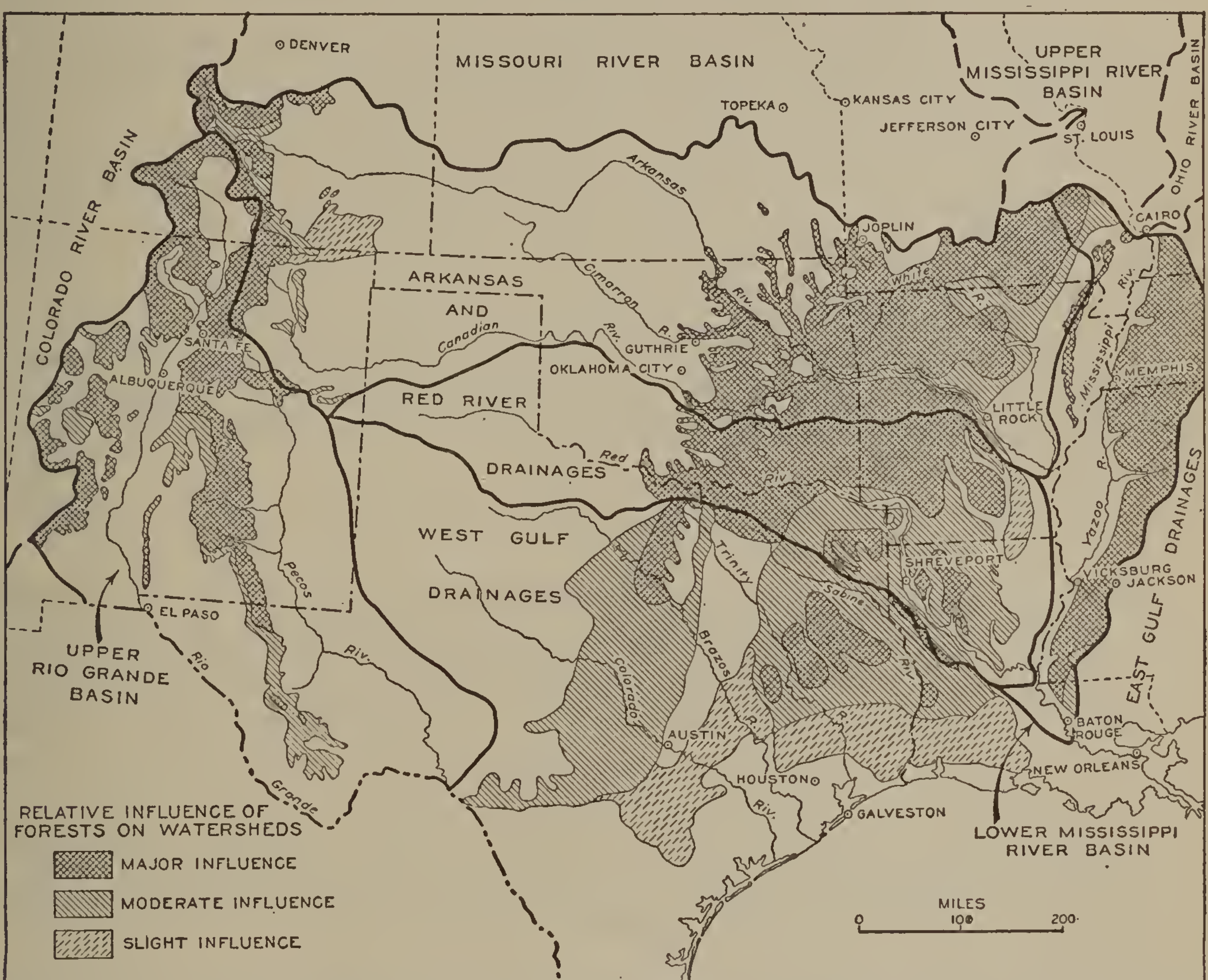


FIGURE 6.—West Gulf drainages, Arkansas—Red River drainages, upper Rio Grande Basin and lower Mississippi River Basin.

about 15 inches in the arid region of western Texas. In the latter region evaporation rates are high and this tends to decrease further the supply of moisture available for plant growth. However, a tendency to torrential rainfalls in some portions of the basin makes annual averages unreliable indexes of true rainfall conditions, as in central and western Texas where a single heavy rain may account for as much as two thirds of the average annual precipitation. In eastern Texas and in the Gulf region intense rains are also common but they seldom reach cloudburst proportions. The maximum rain recorded in the Trinity River watershed is 5½ inches an hour and over 10 inches in 24 consecutive hours.

The fact that these torrential rains are most frequent during the winter when pasture and range are least protected and cultivated

lands are totally unprotected has an important influence in promoting a high run-off ratio. This in turn is reflected in floods, soil erosion, and decreased ground water supplies, especially in the more arid and sparsely vegetated portions of the basin.

## STREAMFLOW PROBLEMS

### CHARACTER OF FLOW

The streams of the basin are in the main perennial. In western Texas the headwater tributaries of the Brazos and Colorado Rivers are, however, dry for large portions of the year. The greatest range in flow is found in arid regions of torrential rainfall in central and western Texas. According to records of the Geological Survey the Little River, a tributary of the Brazos, had a maximum daily flow over a 14-year period of 647,000 second-feet and a minimum flow of only 3 second-feet. The Brazos River at Mineral Wells, Tex., has been completely dry on several occasions during the last 6 years and has had a maximum daily flow of 95,600 second-feet. The Colorado River at Austin, Tex., has varied over a 32-year period from 151,000 to 13 second-feet.

On the other hand, the Sabine River, draining a catchment basin having heavy rainfall and forests covering approximately 43 percent of the total area, fluctuates far less than the streams draining more arid contry, varying over a 6-year period at Ruliff, from 61,200 to 372 second-feet.

### FLOODS

Floods are relatively common in all the drainages. In the Brazos and Colorado River drainages in central and western Texas, severe floods have been occurring at least once in a decade, caused as a rule by local rains of high intensity and rendered doubly destructive because of the lack of an adequate cover on the watersheds. The flood of 1900 caused the failure of the Austin Dam on the Colorado River and flooded large areas of bottomland from Austin to the Gulf. The Brazos flood of September 1921 is reported to have cost the lives of 164 people and damaged property to the extent of more than $12,000,000.

Floods are even more common in the Trinity River drainage, occurring most frequently during spring and fall. According to Weather Bureau records, overflows in the vicinity of Dallas, Tex., have averaged about 4 a year during the last 8 years, and the Trinity River at Trinidad, Tex., has been at flood 33 times in the last 8 years. Both of the above stations are located in the black waxy belt—a region of heavy but productive soils practically all of which are in cultivation. On the Sabine River floods occur almost annually, but they are seldom general throughout the drainage and are most frequent during the winter months as the result of heavy rains of rather local occurrence.

### STREAM-FLOW UTILIZATION

The streams of the West Gulf Basin are and apparently must be relatively unimportant for navigation and the development of hydro-electric power, owing largely to uncertain flow and heavy silt loads.

Water supplies for domestic use and irrigation are reported to be critically low in the arid portions of the basin. Irrigation is locally important on the Nueces and Concho Rivers and to a minor extent for rice growing near the mouth of the Sabine-Neches drainage.

### SILTING OF CHANNELS

The streams of the west Gulf Basin are normally clear but during periods of flood carry enormous quantities of soil eroded from the watersheds. Ashe [33] states that the silt burden of the Colorado River is roughly estimated at 1 percent of its volume or an average of 18,000 acre-feet a year; and that the Brazos River, above Waco, with a drainage area of 30,000 square miles, carries more than 3,200,000 tons of soil a year. Records of measurements made in the Brazos River at Rosenberg over an 8-year period by the United States Bureau of Agricultural Engineering, cooperating with the Texas Board of Water Engineers, show that the maximum monthly silt load carried during a flood period by this river was the 20,000 acre-feet carried in May 1930.

Direct evidence of the economic significance of these silt loads are cited by Ashe who states that the ill-fated Austin Dam on the Colorado River, which broke after only 10 years of service, had its storage capacity reduced 56 percent as a result of silting. The new reservoir constructed in 1913 had by 1922 lost 84 percent of its capacity through silting.

Flood waters of the Trinity and Sabine Rivers are also quite muddy. The Trinity River has overflows known locally as "black floods" and "red floods", depending on whether the storm occurred in the black waxy belt or in the regions of predominantly red soils. These heavy soil loads are, however, considered by engineers to be much less than the huge quantities transported by the Colorado and Brazos Rivers.

### EROSION PROBLEMS

Extremely active erosion of the badlands type is occurring in a region in northwestern Texas known as the "Breaks." This escarpment, between the high plains on the west and the red prairies of Edwards Plateau, varies in width from 1 to several miles and is intricately dissected by the headwater streams of the Colorado and Brazos Rivers with many steep and unstable slopes—the zone of active erosion extending out along the water courses into the red prairies.

In central Texas, along the border of the Edwards Plateau, standing 400 to 1,000 feet above the coastal plain, the streams have cut deep channels and have converted the original plateau edge into a ragged escarpment of mesas, buttes, and rocky canyons. In many places over an extensive area the relatively thin soil has been removed, leaving the parent rock exposed. Moisture conditions are not particularly favorable for tree growth, hence it is largely only where cool exposures exist or when a deep soil occurs that the forest is able to maintain itself. The stand is open and the woods frequently occur as merely scattering patches interrupted by grassy openings. In such locations, any marked disturbance to the cover results in erosion, which when once under way progresses for a considerable period before

[33] Ashe, W. W. Financial Limitation in the Employment of Forest Cover in Protecting Reservoirs, U.S.Dept.Agr.Bul. 1430, 1926.

the vegetation can stop it. On steep slopes such erosion often continues unchecked by any possible vegetational control.

In the eastern portion of the region and more particularly in the Trinity, Sabine, and Neches watersheds, cultivation has led to equally severe erosion. Extensive surveys by the Southern Forest Experiment Station indicate that erosion in these drainages is largely confined to areas in cultivation or to those worn out and abandoned. The data indicate that a million acres of such land is badly eroded, about one fourth of it in the black waxy belt and "cross-timbers" region, and three fourths within the upper coastal plain. In the upper coastal plain nearly 2 million acres of formerly arable land is now lying idle, and of this about 250,000 acres is barren and actively eroding.

The above estimates are undoubtedly very conservative since they take no account of sheet erosion on many of the cultivated fields. Experimental data obtained by the Bureau of Chemistry and Soils, the Texas Experiment Station, and other agencies have demonstrated that in the agricultural sections of Texas soil losses from very gentle slopes are enormous. Bennett[33a] states that at the Spur substation of the Texas Agricultural Experiment Station, in west Texas, 40.7 tons per acre of soil was removed from a 2 percent slope of fallow land by a total rainfall of approximately 27 inches. Gullying is by no means as rapid on these drainages as on similar land in the silt loam uplands of the lower Mississippi Basin. As a rule, gullies more than a few feet in depth are not common.

## FORESTS OF THE WEST GULF DRAINAGES

### CHARACTER AND EXTENT

The forest area of the west Gulf drainages is estimated as 36,736,000 acres, or about 30 percent of the gross area of the basin. Less than half of this consists of true forest, the remainder includes sparsely stocked areas of scrub oak, juniper, mesquite, and chaparral which predominate throughout the zone of meager tree growth in central and western Texas. The areas of commercial forest, made up of two major types—the longleaf pine and the shortleaf-loblolly hardwoods—occur entirely in the eastern part of the basin and are limited mostly to the upper coastal plain portion of the Sabine, Neches, and Trinity watersheds.

The long leaf pine forests, restricted almost entirely to the lower part of the Sabine drainage, have been so heavily cut over as to be practically denuded and to be restocking only very slowly if at all. Were this condition to exist in a region of steep slopes, at the head of important streams, the situation would be disastrous. Here, however, although run-off is probably greatly encouraged, the relatively level topography and the abundance of protective ground cover serve to hold the soil. The soils of the long leaf land are too low in fertility to be extensively cleared for agriculture. The National Forest Reservation Commission has approved the purchase of 24,575 acres of cut-over long leaf land in west central Louisiana, of which 17,965 acres have already been acquired.

The remainder of the commercial forest consists largely of upland stands made up of shortleaf or loblolly pines, or both, in mixture

[33a] Bennett, H. H., and Chapline, W. R. Soil Erosion a National Menace. U.S.Dept.Agr.Circ. 33, 1928.

mainly with such hardwoods as mixed oaks and hickory. On alluvial bottom lands ash, sweet and black gum, magnolia, sycamore, and other moisture-loving species are included. Upland stands are seldom cut clear and an abundance of smaller trees and reproduction is customarily left. Cut-over areas within the range of the pines restock at a very rapid rate as a rule. Large areas of the pine-hardwood lands cleared for agriculture have been abandoned because of erosion, but observations indicate that many old fields are taken over within 5 or 10 years by shortleaf and loblolly pine reproduction which tends to check gullying and to heal lesser forms of erosion.

More than half of the commercial forest area is unprotected from fire and an average of 865,944 acres of this area, largely in long leaf pine, was burned over annually during the years 1926 to 1930 inclusive. These ground fires, usually set by livestock owners during the winter season, destroy the forest litter and are so frequent as to prevent the accumulation of duff and other surface debris, thereby lessening the protective efficiency of the forest cover.

In the Edwards Plateau and "cross-timber" regions of west central Texas the predominant cover consists of scrub oaks, juniper, elm, hackberry, and other species, except along the water courses, where elm, cottonwood, sycamore, and other water-demanding species tend toward luxuriant growth. Toward the west, the scrub species give way to mesquite and shrubs which merge into the grassland of the prairies and high plains of western Texas.

The scrub forests of the plateau region are seldom cut extensively, although they are an important source of firewood, fence posts, and other products for local use. The heaviest inroads have been made in the cedar stands. The scrub oak and juniper stands as a rule do not form a continuous forest but often occur as scattering woodland interspersed by areas of grassland which, particularly those in the western portion of the plateau, furnish range for large herds of livestock. Heavy and unregulated grazing, the rather thin soils of the region, and the lack of adequate rainfall all combine to keep ground cover in a rather depleted condition. Bray[34] describes the transition from former prairie to scrub-oak woodland that has occurred in this region as the result of overgrazing and a decrease in the number of fires. He also cites the spread of mesquite and shrubs over cattle country in central Texas.

According to Bray, fires have become relatively infrequent throughout the Edwards Plateau since settlement of the country, but during dry seasons they occasionally do considerable damage to juniper stands.

### RELATION TO WATERSHED PROBLEM

Experimental studies carried out in northern Mississippi by the Forest Service point to the influence of similar forest cover on the west Gulf drainages in preventing surface run-off and regulating stream flow. Data obtained in 1932 in the upland watersheds of the Yazoo River during a flood period show that less than 0.5 percent of 27 inches of rain falling on an undisturbed oak forest ran off the surface while 62 percent ran off a cultivated field. Other data obtained in May 1930 by the United States Bureau of Chemistry and Soils in the fringe forests of Oklahoma show that surface run-off from burned

[34] Bray, W. L. The Timber of the Edwards Plateau of Texas. U.S. Dept. Agr. Forestry Bul. 49, 1904.

scrub-oak woodland was 110 times that from a comparable unburned area. In the light of these studies it would seem that similar forest in the west Gulf Basin would exercise a like influence.

Of the total forest area of some 37 million acres, about 3 million acres is classed as exerting a major influence on watersheds (fig. 6). In east Texas the highly protective forests consist of rather well-stocked stands made up mostly of shortleaf pine and mixed oaks and other hardwoods. They occur on hilly portions of the upper coastal plain where the heavy and rather erosive clay soils and hilly topography tend to limit the absorption of rainfall and make for a high run-off ratio. Approximately 2 million acres of this protection class occurs in the Sabine and Trinity drainages. In west Texas the forest exerting a major protection influence is the sparse woodland largely in the Breaks region where a cover is essential to stable soils and to decreased flood run-off. It is felt that if more were known of this region, a much larger area would be classed as having a major influence.

Roughly, 21 million acres of forest are classed as having a moderate influence on watersheds. This class includes not only the well-stocked stands of pine-hardwoods in the coastal plain portion of the Trinity and Sabine drainages but also the more extensive scrub oak forests of central Texas.

About 11 million acres of forest in regions of mild topography where the soils are little subject to erosion and surface drainage is not excessive are classed as having only a slight influence on watersheds. They occur in the lower portions of the main drainages, i.e., in the interior flatwoods, coastal prairies, and the more level portions of the upper coastal plain. Another 2 million acres of forest located on alluvial bottom lands are classed as having no influence on watersheds, though some of them are beneficial in holding the stream banks against erosion.

## WATERSHED NEEDS

In general, watershed conditions throughout the West Gulf Basin are far from satisfactory. The prevalence of floods, the inadequacy of water supplies in certain sections, and the extent of erosion all indicate that present vegetative cover is not adequate. The forests are too open, litter is absent, the forest is returning but slowly to denuded lands, and the ground cover is badly depleted.

Of the forestry measures aimed at improving watershed conditions it appears probable that the establishment of new forests will play a minor part. The data collected by the Forest Service in 1932 indicate that of approximately 2,775,000 acres of abandoned fields in the eastern half of the region where climatic conditions permit the growing of commercial forests, about 1,250,000 acres are seriously eroding. However, a very large part of this land is in the upper coastal plain where, given protection, tree reproduction and other native vegetation can be depended on to reclothe the land rather quickly and to check erosion within a few years. Reforestation is needed, however, on about 250,000 acres of badly eroded land. On the remaining abandoned lands some kind of vegetation has already become established. This is serving to hold the soil and, if protected from fire, a forest will gradually take possession and develop more favorable conditions of stream flow.

Improving present forest cover, however, offers a considerable opportunity for combating the watershed problems of portions of the basin. Fire protection on some 8 million acres of unprotected commercial forests would promote the accumulation of forest litter and other ground cover. The extensive scrub forests of central Texas and of the "Breaks" region are, however, in greatest need of improvement. Here fire protection and probably less cutting would do much to encourage scrub oak, mesquite, and other chaparral species. A number of authorities have commented on the deleterious effects of the heavy grazing in this region as contributing to the depletion of the original grass cover. Proper management of livestock to prevent overgrazing, therefore, appears to be the outstanding requirement for improved watershed protection.

In view of the fact that most of this land is in private ownership and that the private owners probably will be financially unable to adopt those corrective measures for the eroded abandoned land which will make for the control of erosion and favorable conditions of stream flow, public ownership appears needed. This ownership should include about 2,300,000 acres of land in those parts of the region where watershed conditions are most critical and where the forest cover exerts a major influence. This would mean about 400,000 acres of abandoned agricultural land and about 1,900,000 acres of forest land. However, as cover conditions and watershed relationships in the West Gulf drainages are imperfectly known, it is more than likely that a much larger area should be in the hands of the public. The lack of specific information as to erosion-control methods indicates that investigations are needed and that these are particularly necessary in the "Breaks" region.

## ST. LAWRENCE RIVER BASIN

The St. Lawrence River (or Great Lakes) drainage in the United States amounts to nearly 85 million acres, of which about 50 percent is forest land. The western portion of this basin is shown in the map of the upper Mississippi River Basin, figure 7; the eastern is shown with the northeastern drainages in figure 3. The forest areas of the basin are classified according to watershed-protective influence as follows: Major influence, 5,029,000 acres; moderate influence, 4,112,000 acres; slight or no influence, 33,105,000 acres.

The relative slightness of forest influence on watersheds in this drainage is more marked in the western half than in the eastern. It is due largely to the fact that much of the St. Lawrence drainage has been heavily glaciated and that large parts of it, particularly in the west, are without marked topographic relief. Throughout many parts of the drainage occur the gravelly and sandy hills and rolling lands typical of glaciated regions. Extensive areas of outwash plains occur, the sandy soils of which are highly absorptive.

The comparative uniformity of the water level in the Great Lakes is due to the very large areas of water and of absorptive soil surface in the drainage rather than to the influence of forest cover. Water supplies are ample. On certain areas in the drainage, however, from a watershed standpoint, a forest cover is necessary.

## DUNE LANDS

Dunes occupy only a narrow strip of land along the eastern shore of the Great Lakes. In many places the width of this strip is scarcely half a mile; in some it is as much as 10 miles. The area involved is probably not more than 125,000 acres. Locally, however, the dunes do considerable harm. As they migrate eastward under the prevailing westerly winds they become a constantly increasing menace to tillable lands and to improvements. They have invaded factory yards in Gary, Ind., and have repeatedly encroached upon railroads and highways.

Usually a scattered stand of oaks or a low, shrubby vegetation occurs on the dunes. Where this cover is complete, it holds the sand in place. Cutting, fire, and trampling by recreationists have so deteriorated the cover that many of the dunes, formerly stable, are now in motion.

A problem akin to that of the shore dunes has developed in New York west of the Adirondack Mountains. As a result of cultivation the top soil has eroded away, exposing fine sand. Unless held in place by a plant cover, this sand moves easily with the wind and in places forms inland dunes. The uncovering of this sand and its movement have led to abandonment of agricultural land which according to census data has caused the area of crop land in these counties to decrease by from 10 to 20 percent. Undoubtedly this condition has been responsible for a considerable part of the farm-land abandonment in St. Lawrence, Lewis, Oswego, and Jefferson Counties. In an effort to control this soil movement the State of New York has purchased many abandoned farms and is reforesting them.

## MOUNTAIN AREAS

The roughest lands in the St. Lawrence drainage are in the Adirondacks and the Green Mountains. Here heavy precipitation, steep slopes, and heavy soils make for rapid run-off and for erosion from cleared lands. For the most part these mountains sustain a hardwood and spruce forest that protects the soil.

On State lands in the Adirondack State Park good cover conditions are safeguarded by a constitutional prohibition of timber cutting. Areas in private ownership within the park, however, are subject to cutting. On these the present selective cutting, winter logging, and infrequent fires disturb the soil but slightly. The land cut over is soon reclaimed by hardwood sprouts. Poor cover conditions brought about by earlier over cutting and by heavy summer fires are gradually improving under fire protection. The State plans to acquire additional lands within the park area.

In the Green Mountains, with their more rolling terrain, a larger area has been brought under cultivation than in the Adirondacks. Abandonment of cultivated lands is common, owing in part to sheet erosion of the heavy soils. In the hardwood stands logging and other disturbances are not destructive. Much of the cutting is done by farmers in the winter, the fire hazard is low except for dry grass in abandoned fields, and there is little grazing on forest lands. On no class of forest land does the forest cover have difficulty in reestablishing itself except on abandoned agricultural land.

## OTHER AREAS

Elsewhere in the St. Lawrence drainage, rather localized problems exist. In the drainage to Lake Ontario in New York and to Lake Erie in northeastern Ohio, erosion is taking place on cultivated lands and local floods occasionally do damage. On areas that have not been cleared for agriculture, the cover is usually sufficient to hold the soil and to maintain favorable conditions of water flow. Cutting has little disturbing effect on the cover, because of the sprouting capacity of the hardwoods, and serious fires and extensive overgrazing are in general absent. On abandoned farm lands the forest has great difficulty in reestablishing itself naturally.

The most wide-spread type of erosion, although probably the least recognized, is slow sheet erosion on the soils of the Volusia series. This is particularly severe on the cleared hill lands of western New York, and is common also in northeastern Ohio. Studies by Professor Barron and associated pasture specialists, of Cornell Univesity, indicate that on these soils sheet erosion, acting since the land was first cleared, is an important factor in decreasing soil fertility and leading to land abandonment. On many hill farms sheet erosion manifests itself in an increasingly stony condition of the surface as the finer top soil is gradually washed away. In extreme cases the surface soil of the steeper slopes, largely in pastures, becomes too shallow for further cultivation.

In a study made by G. R. Stewart at Cornell University, the permeability of fertile hardwood forest soil was compared with that of run-down pastures on the same soil types. The forest soils were found to be more permeable to water and more retentive of water. All grass lands compared with the best forest soil showed a poorer physical condition. The greatest difference was shown by the run-down poverty-grass pastures located on the compact Volusia soils. Here water passed into the soil very slowly. It is on such compact soils that much farm abandonment occurs. Census data show marked decline in the past two decades in the crop land of Ashtabula, Geauga, Trumbull, Summit, and other counties in Ohio, in Erie and Crawford Counties in Pennsylvania, and Chautauqua County in New York. Compact soils are general in these counties.

Another type of erosion on agricultural lands takes place on the deeper soils. This consists of sudden breaks or gullies that may form in a few days' time when the top soil is fairly well saturated with water, as in the early spring. It is especially marked on the steeper hillsides. This more serious erosion, according to Professor Barron, probably grows out of sheet erosion and a decrease in the fertility of the soil. It is reflected in a poor growth of grass in the spring. The thin sod is easily broken by cattle and a small gully, once formed, grows rapidly. Such gullying was found by the Northeastern Forest Experiment Station to be not at all uncommon in the Genesee River Valley, from the headwaters of the river to the lower levels adjacent to Conesus Lake. Gullies of this type combine and grow steadily in each season of heavy rainfall. A decline of from 15 to 20 percent in crop land, reflecting this situation, is shown by census data for such New York counties as Genesee, Wyoming, Cattaraugus, and Allegheny. New York State has taken a positive step toward bettering conditions on eroded lands by acquiring and reforesting such lands. New York

municipalities, also, have acquired lands on the watersheds from which they obtain their water supplies and planted them with trees. At the rate at which public ownership and management are now progressing, however, many years would be required to bring about good forest cover conditions on all the abandoned agricultural lands in this drainage that have watershed-protection value.

In the western part of the St. Lawrence drainage, although forest depletion is extensive, no serious erosion or watershed troubles have been reported. In the upper peninsula of Michigan and along the north shore of Lake Superior a complete forest cover prevents erosion. Here the slopes are steeper than in many other sections of the Great Lakes region and deforestation would lead to rapid run-off and severe erosion.

### SUMMARY

Although the forest lands of the St. Lawrence drainage, except in the Adirondack State Park, are in poor shape from the standpoint of commercial forestry, because of cutting and fire in the past, yet these forest lands are not in a serious condition from the standpoint of watershed protection. Some areas, such as the sand dunes, will require special treatment if erosion is to be stopped, but in general rather simple measures of forest management and fire control will meet the objectives of watershed protection. Estimates indicate that about 500,000 acres are in need of planting, and about 50,000 acres are in need of some special form of treatment to help stabilize the soil.

The present survey of existing conditions shows that in the region of major influence, an additional area of about 1 million acres should be in some form of public ownership. About 300,000 acres of the total are the abandoned agricultural lands, and 700,000 acres are other forest lands. Just what form this ownership should take, whether national, State, or local, depends upon the interest and ability of the agency involved.

## HUDSON BAY DRAINAGES

The drainage to Hudson Bay includes some 40,000 square miles of land in northern Minnesota and North and South Dakota, practically all of which is drained by the Red River of the North and its tributaries (fig. 10). The Red River is a lazy, meandering prairie stream that winds through a broad agricultural valley, the terrain of which is without notable relief.

About 25 percent of the Hudson Bay drainage can be considered forest land. By far the larger part of this is in Minnesota, where the prairie transition forest appears at a distance of from 30 to 50 miles from the river, on the first important rise of ground. The outer fringe of the transition forest is of bur oak and associated prairie tree species. At greater distances from the river occur swamp forests, once principally of spruce. By reason of cutting and fires, the spruce has largely given way to aspen. Not much pine is present except on the better-drained soils toward the eastern edge of the drainage. Open oak forests again appear on the Pembina and Turtle Mountains in North Dakota, on the international boundary. On the sandier soils of North Dakota, such as the uplands about Devils Lake, and along the streams, occur some severely culled small forests.

The small quantity of forest along the stream courses and the small scattered areas of upland forest in North Dakota are insufficient to have much effect on the flow of the Red River. They are important in preventing erosion. Some erosion has followed cutting on the Pembina and Turtle Mountains in North Dakota, but it is of little consequence except very locally. Recreational use, which would preserve watershed values, might conceivably be the best use for this hill land, because of the absence of nearby recreation areas on the American side and because the Canadian half of the Turtle Mountains is managed for recreation.

Some of the spruce forest swamp areas in Minnesota have been drained for agricultural use, but increasing abandonment of cleared lands indicates that these areas are probably submarginal for agriculture. As the ditches become clogged following disuse, the forest is gradually taking possession again.

In the Red River Valley windbreaks and shelterbelts have been planted about farm buildings. Their aggregate area is not large, and they have little, if any, bearing on stream conditions. Further tree planting, desirable from the standpoint of farm comfort, would have little if any effect upon the streams.

## UPPER MISSISSIPPI RIVER BASIN

The upper Mississippi River Basin is that portion of the area north of the Ohio that drains into the main river. It includes some 15 percent of the entire Mississippi drainage system. It is divided roughly in two by a line running in a northwest and southeast direction through Minnesota approximately at St. Paul and so continuing through Wisconsin. In the present discussion the two divisions will be referred to as the northern or heavily glaciated area and the southern or silt loam uplands area.

Both areas have been severely glaciated, first by ice sheets that extended as far south as the Missouri and Ohio Rivers and later by the Wisconsin stages, which reached central and southeastern Wisconsin and central Minnesota. The earlier glacial soils are largely till, in which clays predominate. Silt loams are common in the old lake beds. The Wisconsin advance was so recent that the topography, drainage, and soils of the deposit have been but little modified. Consequently sands and gravels predominate, although clay deposits have covered some of the sand. In the older glaciation, the land is for the most part level or gently rolling. In the northern area are pronounced moraines and drumlins, some of them sufficiently prominent to form the divides between such Wisconsin rivers as the Chippewa, Black, Wisconsin, and St. Croix.

On the areas more recently glaciated the sandy soils support a pine forest and the heavier soils support hardwood stands in which beech, maple, elm, and ash are common. The swamps, some of which are of considerable size, contain spruce, fir, cedar, and tamarack. The heavier soils of the older glaciation having weathered and leached more, support oaks, hickories, walnuts, and other typical upland species.

A small area escaped glaciation. This driftless area lies chiefly in southwestern Wisconsin, and extends into Illinois, Iowa, and Minnesota. Here the deep soils, derived from parent rock, are highly

erosible. This old plain was thoroughly dissected by normal erosion probably even before the advance of the ice on neighboring areas.

Deposits of loess are a distinctive feature of the upper Mississippi Basin. These are found for the most part east of the Mississippi River, though extensive deposits are found also in Iowa and Missouri. The loess is thick about the terminals of the ice sheets in northeastern Iowa and southern Illinois. Away from these borders it thins out on interstream areas, although it retains its thickness along the larger valleys. It occurs commonly on bluffs immediately overlooking the valleys. Under a vegetative cover it is very porous and absorptive. On this loess soil oaks and other upland species predominate.

These physiographic features are largely responsible for the watershed-protective classification given the forest area of the upper Mississippi River Basin. Of the total 28 million acres only slightly more than 10 million acres is classed as having a considerable measure of influence upon watershed conditions. The lands so classed occur principally in the southern half of the basin, on loess areas and driftless areas and in the uplands of the older glaciation. In the northern division, the areas of greatest influence upon watershed conditions lie in the large moraines at the head of the Chippewa River. Some 5,700,000 acres of forest is classed as having a major watershed-protective influence, and 4,430,000 acres as having a moderate influence. The remaining area is considered to have relatively slight influence largely because of the absorptive nature of the soil and the presence of numerous lakes and swamps. The areas ascribed to each class are shown in figure 7.

The average annual precipitation totals 25 to 30 inches in Minnesota, 30 to 35 inches over the Wisconsin portion of the basin, and more than 35 inches in some parts of Illinois. Most of the precipitation occurs during the spring and summer months. Snowfall averages between 40 and 60 inches in the north, and from 20 to 30 inches in the south. Rainfall of more than 1 inch in 24 hours sometimes occurs four times in a single year in the northern part. In the southern part, 24-hour rainfall exceeds 1 inch still more frequently, exceeds 2 inches as often as once a year, and has been known to total 4 inches.

Local floods are not uncommon. In the north, "freshets" rather than major floods occur. Occasionally severe floods occur in the southern streams as a result of rapid snow melt. The high percentage of cleared land is a factor in these floods, because so much of the cultivated land is without a cover crop during early spring.

## HEAVILY GLACIATED REGION

In the heavily glaciated region the character of the terrain and soils makes for low run-off. In much of the region hills are either of gentle slope or largely of gravel. Outwash sand plains are comparatively flat. The sands provide a large absorbing surface, and much of the land characterized by heavier soils is poorly drained. The stream-flow regulation effected by the many swamps and lakes is supplemented by artificial reservoirs.

Forest conditions have greatly changed in the last century. Settlement, which began in the prairies and in the scattered oak forests of southern Wisconsin, gradually spread northward and westward into the more densely forested areas. Extensive tracts were cleared and put into cultivation. Timber cutting followed closely upon agricul-

tural development. So far has the removal of the old-growth timber progressed that almost any tree that will saw out a board is marketable.

Cutting has not been solely responsible for the change in the forest cover; fires have been common and extensive. On the cut-over areas fires destroyed what timber was left after logging. Fires have occurred repeatedly on many of the cut-over areas, making conditions even more unfavorable to future forest growth.


FIGURE 7.—Upper Mississippi River Basin and upper portion of St. Lawrence River Basin.

The conifer forest, destroyed by fire and cutting, has been replaced by such cover types as sweet fern, brush, aspen, fire cherry, or birch. On some areas an oak woodland type has developed, and on others with sandier soil a jack pine woodland has appeared.

Because the soils at the headwaters of the Mississippi are for the most part very porous, it is possible that even the destruction of the humus has not materially changed their capacity to absorb and hold water.

Although cutting and fire have depleted the hardwood forests, regrowth has taken place rather promptly. When the mature forest has been destroyed, coppice and other new growth have taken possession. Hardwood litter helps to increase soil fertility and porosity. On hardwood areas, particularly in the rather rough country at the head of the Chippewa River, the forest cover prevents erosion of the fine soil that would easily be floated away.

### SILT LOAM UPLANDS

Only about half the upland area was originally occupied by forests. The most extensive of these forests were in southwestern Wisconsin and northwestern Illinois, and in southern Illinois and southeastern Missouri. The others existed as scattered areas of woodland in the prairies and in the bottom lands. Toward its western edge the basin was practically treeless.

Some of the forests were exploited commercially. In the lead region of northwestern Illinois and in the limestone areas, extensive fuel-wood cuttings were made. Commercial timber production for other than local needs prevailed in the bottoms, particularly in southern Illinois. Although fires were a usual concomitant of cutting, devastation was prevented by the fact that the forests were largely of hardwoods which sprouted.

In the prairie region, small areas of the scattered original forests remained as farm woodlands. These have been repeatedly culled and most of them have been pastured. Culling has left only the poorest trees, and in many instances pasturage has grown so heavy as to prevent tree reproduction.

The upland soils were very fertile and very absorptive when first put under cultivation, because of the accumulations of organic matter. Agriculture gradually exhausted the humic deposits. Sheet erosion increased as the humus was dissipated. On the hilly lands it soon developed into small shoestring gullies, and these rapidly grew into more serious gullies.

Severe gullying took place wherever water collecting on the plateau lands ran over the bluffs. It has now gone so far that on many hill lands it prevents the farmers from reaching some of their fields with farm equipment.

### INFLUENCE OF FOREST COVER ON WATERSHED CONDITIONS

Because the silt loam soils of the uplands are eroded so easily when bare, the forest cover on them is classed as having a major watershed-protective influence. That a forest cover maintains favorable conditions of water flow on these upland soils is shown by observations of the Lake States Forest Experiment Station as to run-off from summer rains in southwestern Wisconsin.[35] Data from these investigations show that the run-off from pastures that have been cleared, plowed, and seeded, as well as from areas in timothy, clover, or alfalfa, is approximately the same as that from cultivated fields. Seeded pastures, because of close cropping, packing of soil, and slopes generally steeper than those prevailing in fields, were the largest contributors to run-off.

[35] Bates, C. G., and Zeasman, O. R., Soil Erosion, Wisc.Agri.Expt.Sta.Res.Bul. 99, 1930.

Not only did the timbered lands produce a negligible run-off but there was no erosion from such areas.

As shown in these investigations, the effectiveness of forest stands of different densities in holding back run-off on these uplands varies materially with density of stand and intensity of grazing.

## BEHAVIOR OF SMALL STREAMS

Although reliable quantitative measurements on intermittent small streams are unavailable, field observations indicate that those originating on field and pasture areas may yield 50 percent or more run-off from hard rains. Thus a watershed of 100 acres may readily develop a stream the peak flow of which exceeds 100 second-feet. It would be virtually impossible for such a flow to be developed by an area having a complete forest cover.

Of greater interest is the behavior of permanent small streams draining watersheds so small that the entire area is likely to be affected by a single local storm. A watershed area of 5,000 acres, for example, may deliver normally a stream of about 5 second-feet. Under extreme conditions such a stream may be swollen to 800 or more times its normal volume, developing a peak flow of 0.8 second-foot per acre of watershed. On larger watersheds, although under similar conditions the total flood volume may be proportionately the same, because of the greater length of stream and greater diversity of watershed conditions, there is a tendency for the flood to be relatively more prolonged and for the peak flow to be relatively lower.

The flashy run-off of the small streams is strikingly illustrated by Gilmore Creek, near Winona, Minn., having a watershed area of only about 15 square miles, of which about 40 percent has been cleared and having, under normal conditions, a discharge of 10 second-feet. During August 1932 the discharge of this stream rose in 2 hours to nearly 5,000 second-feet, sweeping everything in its path, including finally the concrete weir at which the discharge was measured. Such phenomena have not been infrequent in the history of this stream since the advent of agriculture.

## SILT LOADS OF STREAMS

According to conservative estimates by the Lake States Forest Experiment Station based on sampling, the Wisconsin River carries 2 million cubic yards of silt, despite the fact that some of the load from the upper three fourths of its drainage now settles above power dams. A proportionate silt contribution from the Black River, on which conditions are similar, would probably be about 1 million cubic yards annually.

The smaller streams that rise within the unglaciated area are likewise heavily loaded with silt. Their contributions of water may never be large enough to affect appreciably the flow of the Mississippi, but they bring silt loads entirely disproportionate to their water discharges. Temporary streams that empty directly into the Mississippi often carry 5 to 10 percent of solid matter. Larger and more permanent streams such as the Buffalo River sometimes carry 5 percent of silt to their outlets.

## EROSION OF AGRICULTURAL LANDS

Soil surveys recently made in the Central States by various State agencies have revealed some 17 million acres of badly eroded agricultural land on which the continuance of agriculture is at least doubtful under present conditions. Of this total something like 6 or 7 million acres lies in the upper Mississippi River drainage. On these lands farm abandonment is progressing.

The widespread occurrence of erosion is indicated by figure 8, based on data of the Illinois Soil Survey, which shows the extent and distribution of lands "destructively" and "seriously" eroded in Illinois. The field work which this map represents included sampling of every 10 acres. "Destructively eroded" areas are defined by Dr. A. E. Norton, assistant chief of the Illinois State Soil Survey, as "areas which cannot be cultivated by any practical known means at a profit because they erode faster than it is possible to build up the soil. * * *. Within this division there are areas suitable for pasturing, orcharding, and timbering. The percentage of the first two is relatively small in comparison with that suitable for timbering only." Dr. Norton defines "seriously eroded" lands as "areas which can be cultivated by specialized methods for profit. Certain treatment, such as terracing and the application of readily available organic matter, must be given the land before it can be cultivated. No doubt much of it could best be utilized in forests until such time as there is a greater demand for cultivated crops than at present." The Illinois Soil Survey recognizes a third class of eroded land: Harmfully eroded areas are subject to sheet erosion. Unless the methods of agriculture are changed in the future, "this area will some day fall in the destructive erosion division." Land of this class is not indicated on the map. The survey data show some 3 million acres of destructively eroding land, 3 million acres of seriously eroding land, and 12½ million acres of harmfully eroded land.

State soils specialists and State foresters have estimated that between 50 and 75 percent of the more severely eroded land in the upper Mississippi River basin has already been abandoned. Much of this land is almost completely denuded.

According to the results of investigations made by the Missouri Agricultural Experiment Station on loamy soils continuously in corn, a 7-inch layer of soil is removed in 49 years from tilled land that slopes 4 feet in 100. This is at the rate of 20.5 tons of soil per acre per year. It is possible that even greater soil losses have occurred on areas of loess soil such as those in southern Illinois.

In the driftless area, dairying has been extensively developed. There is every reason to believe that it has been overdeveloped. Too much land has been cleared, too large an area has been put into crops and pasture, too much trampling has taken place. Consequently gullying is making it impossible for the industry to continue on its present scale. Although only about one third of the total area cleared is being cultivated, areas under cultivation include much land with grades exceeding 20 percent and occasional slopes with grades of 35 percent. On such slopes erosion, if once started, proceeds rapidly. In Europe, slopes with grades of more than 15 percent are considered unsuitable for cropping. In this country the same belief has long been held by foresters and is coming to be entertained by agriculturists and soils experts.

GULLYING ON CLEARED LANDS

In 1929, the Lake States Forest Experiment Station made a field examination to determine the number and extent of the active

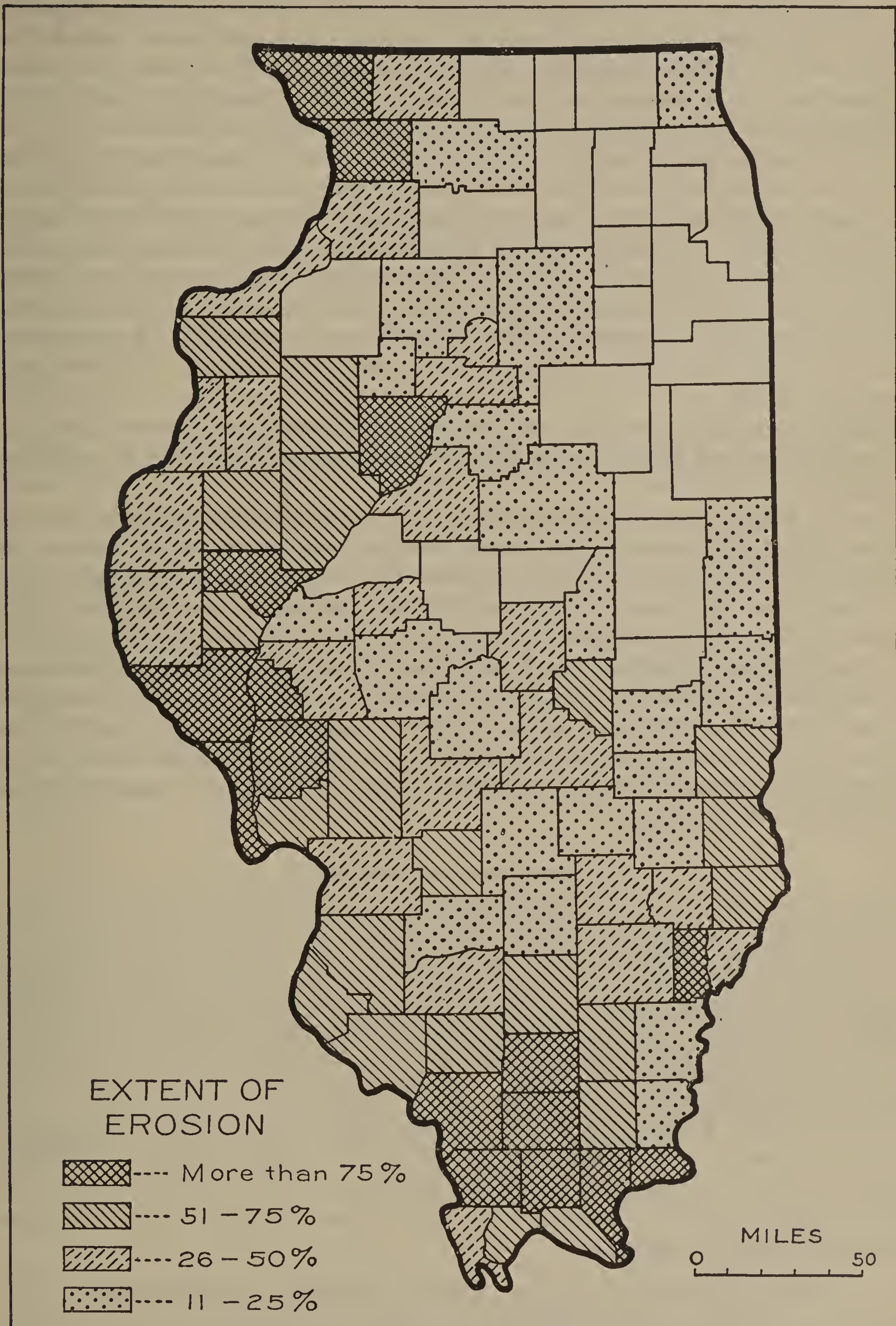


FIGURE 8.—Map of Illinois prepared from data of the Illinois Soil Survey, showing the percentages of county areas affected by erosion of a "serious" and a "destructive" nature combined. (See text for definition of classification.)

gullies in Buffalo County, in southwestern Wisconsin, an area of about 50,000 acres containing the river terrace land along many

miles of the Buffalo River and some such land on tributary streams. From the 170 gullies individually mapped had been removed 3,247,000 cubic yards of soil, or an average per gully of some 20,000 cubic yards. Since on the average these gullies have been active for about 10 years, erosion is removing annually from this small area approximately 300,000 cubic yards of soil, or about 4,000 cubic yards per square mile. With more than 100 square miles in the watershed under cultivation, it is estimated that the average annual silt load of the Buffalo River may total as much as a million cubic yards.

On the adjoining Black River there is no large area where gullying is so prevalent, but some gullies of enormous size have formed in the deep and wide terrace, mostly concentrated in one locality of about 8 square miles. A single one of these gullies has, in about 15 years, dumped directly into the Black River slightly more than a million cubic yards of coarse and fine material. Examination of the drainage revealed 31 active gullies. The volume of soil removed amounted to some 3,850,000 cubic yards, or an average of about 125,000 cubic yards per gully.

Similar conditions exist on loess areas in various places along the upper Mississippi River, as in Calhoun and other counties in southern Illinois.

The fact that so much of the land in the silt loam uplands is being eroded, that the eroded material is dumped so promptly into the Mississippi, and that all run-off from this area is so closely related to the floods in the lower river make this situation one of the really critical national problems. Plans have been proposed for a gigantic waterway system linking the Great Lakes with the Gulf. Because of the excessive erosion now taking place, exceedingly costly dredging would be necessary to construct and to maintain this channel. The silt brought down by streams into the upper portion of the river is creating difficulties for the present 9-foot navigation channel in the upper part of the river.

## GULLYING OF BLUFFS

In addition to sheet erosion and the deep gullying of terrace soils a type of erosion independent of the character of cover occurs on the uncultivated bluff area, induced solely by run-off from the cultivated or pastured ground above. Such run-off is often diverted from natural channels to some artificial channel over the bluff. Even though it left the fields without picking up a heavy load of soil, it is capable of causing immense destruction as it passes over the steep rocky slopes, cutting away the loose residual soil mass, undermining and uprooting trees, and eventually, in extreme cases, causing landslides. Coarse detritus deposited by these streams in the valleys often ruins tillable land, and the torrent of water often destroys roads, bridges, and other improvements.

## MEASURES NEEDED FOR WATERSHED PROTECTION

To prevent erosion on a private property in the upper Mississippi River Basin is often beyond the power of the owner. Effective control can be brought about only through the initiative and participation of governmental agencies. Great as is the local interest of various public agencies, such as the States and counties in these

erosion problems of the upper Mississippi Basin, it is far exceeded by the Federal interest. Nowhere do conditions at the "headwaters of navigable streams" have a more direct and crucial bearing upon Mississippi River problems than in these uplands of Wisconsin, Illinois, Minnesota, Iowa, and Missouri. In few other portions of the United States do erosion conditions approach the seriousness of those of the silt-loam uplands of the Mississippi. The conditions existing on certain eastern mountain areas prior to their purchase for national-forest purposes do not compare with those that now exist on these uplands.

A public acquisition policy is needed. The purpose of such a policy would be first to acquire the more critical areas, plant or otherwise revegetate them, and place them under the form of management that would most quickly develop a full protective cover. Altogether something like 7 million acres in all should be brought into public ownership, including probably 2½ million acres of abandoned farm lands.

Public acquisition would be very difficult. The land involved is held by many small owners, and parts of it are still sufficiently productive that high prices would be asked. The urgency of the situation, however, should prevent these factors from acting as a deterrent. Could sums equal to those that are annually expended for dredging and stream improvement in the upper Mississippi Basin be spent in acquiring eroded land and reconditioning it, the need of continuing this dredging would be largely eliminated.

Planting would be required on at least one third of the eroded abandoned farm lands. This reclamation would be difficult at best; not only has cultivation changed the structure of the topsoil but the subsoil has been exposed over large areas. Investigations are needed to determine what methods of planting should be used.

It would seem desirable to require that on slopes, the grade of which exceeds 10 or 15 percent, a forest cover be restored and maintained.

Special measures of erosion control are needed to reclaim at least 250,000 acres of the most severely gullied land. These would include the use of check dams, soil-saving dams, contouring and ditching, and similar devices. Research is necessary to determine where each of these devices is needed. If erosion proceeds much further, still greater works will be necessary, and over a very much larger area.

Additional fire protection, so badly needed elsewhere, is not urgently required in this basin. Most of the States have very largely attained the objectives set up in the section of this report entitled "Protection Against Fire."

## SUMMARY

In the heavily glaciated portion of the upper Mississippi River Basin watershed conditions are not bad. The forest cover, while helpful, is of relatively little consequence in watershed protection because of the absorptive character of the soils, the large areas of swamps, and the relatively level terrain. Only at the very head of the Chippewa River is there any outstanding need for protection forests. Here a forest area of about a million acres should be managed for watershed protection. Because of the very great influence of this

basin on Mississippi floods, the Federal interest predominates. Good fire control and simple forestry measures will maintain good watershed conditions.

In the uplands portion of the basin, erosion due to farming and pasturage has affected very large areas and is contributing greatly to land abandonment. The eroded soil is being sluiced into the Mississippi River, constituting an added load to a stream that is notorious for the frequent shifts of its channel and for its sand bars and shoals, and necessitating heavy expenditures for dredging to maintain a navigable channel. Abnormal surface run-off, increased by cultivation, swells the flood crests.

The extensive erosion that is now taking place on the silt uplands calls for definite action. One step would be to prohibit clearing of slopes the grades of which exceed 15 percent and to reforest slopes of this grade that have been used for agriculture. Another would be to reduce pasturage on slopes. Action of this kind would call either for public regulation of forest land or for public ownership of something like 7 million acres of land. The Federal aspects of the problem are far more important than the local aspects.

Possibly a half million acres should be planted in order to insure prompt control of erosion and betterment of conditions. Planting alone, however, will not hold the soil where great gullies have formed; the correction of such gullies will require check dams, soil-saving dams, seeding to grasses and weeds as a temporary aid to forest planting, and correction of stream channels. Such extra work will be required on 250,000 acres of the most severely eroded land.

## THE OHIO RIVER BASIN

The Ohio and its tributaries compose one of the most important watersheds in the United States. Although its area of 203,782 square miles is only 16.5 percent of the whole Mississippi River system, the Ohio and lower Mississippi alone can produce a great flood without assistance from the upper Mississippi River or the other tributaries, the latter usually being in moderate flow when the two greater rivers are in flood. [36] The Ohio is the largest eastern tributary of the Mississippi, and contributes on the average 300,000 second-feet to the flow of the greater river. Within its borders about 17,600,000 people or 14.3 percent of our population reside. The region contains fine farm lands, great natural resources, industrial cities, and good markets. The boundaries of the Ohio River Basin in relation to the portions of 14 States which it drains are shown in figure 9.

### TOPOGRAPHY

Wide extremes of surface are exhibited by the Ohio River Basin. In the northern and northwestern portions, level to gently rolling agricultural lands predominate on the drainages of the Wabash, Miami, and Scioto Rivers. The elevation varies from about 300 feet in the Wabash bottoms and 800 feet in eastern Illinois to 1,000 to 1,200 feet above sea level in Ohio. South of these level to rolling lands, although the general elevation does not gain, the country be-

[36] Frankenfield, H. C., 1923—The Spring Floods of 1922. Monthly Weather Review Supplement No. 22, p. 5.

comes more broken and hilly and differences in elevation of 100 to 300 feet in rather short distances are common. Along the Ohio River itself, steep bluffs and highly dissected topography are found from Pittsburgh down to about 50 miles below Louisville, Ky. Within the bluegrass country of Kentucky and the central basin of Tennessee the surface is rolling, but both of these localities are enclosed by rims of higher steep hilly land called the Knobs in Kentucky and the Highland Rim in Tennessee. In the southwestern portion of the basin,


FIGURE 9.—Ohio River Basin.

on the lower stretches of the Tennessee and Cumberland Rivers, rolling to hilly land is found which in places is comparatively rough.

The southeastern and eastern portions of the Ohio Basin are decidedly mountainous in character. They include three distinct provinces, the Blue Ridge, the Appalachian Valley, and the Appalachian Plateau. The Appalachian Valley separates the other two provinces and drains to the southwest as part of the Tennessee River Basin. Within the valley are found long parallel steep-sided mountainous ridges. The Appalachian Plateau to the west includes the Cumberland Plateau of eastern Tennessee and Kentucky and the Allegheny Plateau north of the Kanawha River in West Virginia and Pennsylvania.

Within the Cumberland Plateau, the Cumberland, Kentucky, Big Sandy, and Tennessee Rivers have carved out topography of a highly dissected and mountainous character. Slopes are steep, and ridge tops reach elevations of 4,000 feet. To the northeast the Kanawha, Monongahela, and Allegheny Rivers have dissected the Allegheny Plateau in similar fashion, but the elevations reach only to about 3,200 feet in Pennsylvania. The Blue Ridge in eastern Tennessee and North Carolina attains the highest elevations east of the Rocky Mountains. From a base of about 1,600 feet in the Appalachian Valley, the Ridge rises to high mountainous country containing some 40 peaks over 6,000 feet in elevation the highest of which, Mount Mitchell, is 6,684 feet. Farther north in Virginia, the Blue Ridge reaches an elevation of about 4,000 feet.

## SOILS

In the more level northern and northwestern portions of the Ohio River Basin, the soils are of glacial origin. They are derived from glacial flour and drift resulting from the grinding of limestones, shales, and sandstones. For the most part they include loams, silt loams, and loamy clays, but in places rather light sandy soils are found. They have not developed the porosity characteristic of much older soils.

Most of the rest of the basin contains residual soils formed in place by the weathering of underlying rock formations. Exceptions are the alluvial soils along stream bottoms and river benches, and certain areas of loessial soil in western Kentucky, southern Illinois, and adjacent Indiana and Ohio, along the lower portions of the Wabash, Ohio, and Tennessee Rivers. Large areas of weathered clays, loams, and sandy loams in the hilly and Appalachian Plateau provinces have been derived from shales, limestones, and sandstones. In the bluegrass country of Kentucky and the central basin of Tennessee, the soils are derived from limestone. In the Blue Ridge province the soils are derived from granites, gneisses, schists, and other crystalline rocks which upon disintegration yield light-textured soils. The Appalachian Valley contains soils derived in large part from limestone.

## PRECIPITATION[37]

The average annual precipitation varies from 35–40 inches on the minor drainages north of the Ohio River to 60–70 inches in the Blue Ridge headwaters of the Tennessee River. Throughout most of the lower hilly portion of the basin in Tennessee, Kentucky, and West Virginia the annual rainfall frequently reaches 45–50 inches. Extremes of recorded precipitation range from 19 inches in Illinois to as high as 120 inches in the Great Smoky Mountains of North Carolina.

A relatively small part of the total precipitation comes as snow. The heaviest average annual snowfall, approximately 80 inches, occurs on the headwaters of the Monongahela and Kanawha Rivers. The lowest snowfall is found in the Tennessee River Basin. The average fall of snow north of the Ohio River is about 25 inches.

As a rule, precipitation is well distributed throughout the year, with heavier monthly averages from December to March or April,

[37] Precipitation records cited are taken from Precipitation and Humidity, by J. B. Kincer, U.S. Dept. Agr. Atlas of Amer. Agr. pt. II, A. 1922.

and lighter averages during autumn. Exceptionally heavy precipitation has been experienced in many localities in the basin. Sudden downpours of the "cloudburst" type have been recorded frequently on the higher and mountainous portions of the basin. Concentrated heavy rains covering most of the Ohio Basin have been experienced. During the 4 days, March 23–27, 1913, storms brought from 1.4 to 11.1 inches of rain to various portions of this basin.

## WATERSHED PROBLEMS

### FLOODS

Floods are a recurring event for the population living in communities along the major river and on portions of its tributaries. Speaking of the Ohio River in 1913, Horton and Jackson [38] state than in no year since 1873 has the Ohio River failed, at some point along its course, to overflow its banks and flood large areas of adjoining bottom lands, in some years flooding as many as five times. King [39] recites the disasters on the Tennessee and Cumberland River Basins which have come in 1924, 1926, 1927, 1928, and 1929, and shows that the Cumberland River at Nashville has been in flood 73 times since 1874, or an average of more than once every year.

The primary natural cause of floods in this basin is either concentrated and excessive rainfall over a period of a few hours time, as in the floods of March–April 1907, and of 1913, or, in the northern part of the basin, the unfortunate combination of frozen ground followed by snowfall and warm rains, a condition which was responsible, according to Horton and Jackson, for the 1884 flood.

Among man-made causes, Horton and Jackson list the failure of reservoirs, the breaking of levees, and the constricting of stream and river channels by buildings, factories, abutments, grades, and the like. A fundamental man-made cause of floods, not stressed by these writers, but second only in importance to concentrated rainfall, is deforestation and the disturbance or destruction of soil cover.

The damages which can be charged against floods run into very high totals. Horton and Jackson estimate the damage in the Ohio Valley from the 1913 flood as more than $180,000,000. Of this, it is estimated that Dayton, Ohio, received damage amounting to $100,000,000. Four hundred lives were reported lost. In the same deluge, Columbus, Ohio, lost 3 bridges, more than 4,000 dwellings were inundated, 20,000 people homeless, and 100 lives lost. A review of damages as reported in the Monthly Weather Review indicates that the annual losses from floods in the Ohio Valley have averaged about $4,600,000 for the period 1920–32, exclusive of 1925 and 1931. In Tennessee it is estimated that in the years 1926 to 1930 floods brought losses of $20,000,000, or an average of $4,000,000 a year. The flood of March 1929 destroyed more than 100 bridges in the Cumberland Plateau region and middle Tennessee. King estimates conservatively that floods yearly cost Tennessee $1,000,000.

---

[38] Horton, A. H., and Jackson, H. J. Flood of March–April 1913—The Ohio Valley. U.S.Geol. Survey Water Supply Paper 334, 1913.
[39] King, W. R. Surface waters of Tennessee. Div. of Geol. Dept. of Educ. Bul. 40, 1931.

In the southern Appalachians, Glenn [40] states, the flood loss during 1910 reached some $18,000,000 and in the following year totaled about $9,000,000 more.

The Wabash and White River at flood in January 1930 did $6,862,000 damage (Monthly Weather Review for February 1930). The Southern Appalachian flood of July 1916 did nearly $22,000,000 damage (Ibid., for August 1916).

Records indicate that floods in the Ohio basin are on the increase. Leighton [41] shows by his studies on the three major branches of the Ohio River above Wheeling, W.Va. (the Allegheny, Youghiogheny, and Monongahela), for the period 1885–1907, that "a marked increase in the number of days of floods" is clearly indicated. Table 8 points out the trend in flood increases from 1871 to 1922 in different portions of the watershed of the Ohio Valley. The agreement of data by the United States Weather Bureau for Cincinnati, Ohio, with that for Pittsburgh, Pa., by the flood commissioner, implies that causes of flood increase are similar on the basins of the Muskingum, Kanawha, Scioto, and Big Sandy Rivers to those on the Allegheny and Monongahela Rivers above Pittsburgh. Ashe [42] has indicated an increase in number of days of flood on the Ohio River at Wheeling, W.Va., where the flood stage is 20 feet, from 102 (1838–47) to 220 (1898–1907) and in number of floods from 34 for the early period to 55 for the latter. In the southern part of the drainage on the Cumberland River at Burnside, Ky., he notes a similar increase in the number of floods above the stage of 40 feet (table 8). In the Tennessee River Valley, King anticipates higher flood crests for storms of the same magnitude than those in the past. It is probable that the frequency of floods is increasing here as in the eastern portion of the Ohio basin.

TABLE 8.—*Trend in number of floods, Ohio River Basin, 1871–1922*

| Period | Cumberland River | Allegheny and Monongahela Rivers | | Ohio River | Tennessee River |
|---|---|---|---|---|---|
| | At Burnside, Ky.[1] | At Pittsburgh, Pa.[2] | At Pittsburgh, Pa.[3] | At Cincinnati, Ohio[3] | At Johnsonville, Tenn.[3] |
| | *Number* | *Number* | *Number* | *Number* | *Number* |
| 1871–75 | ---------- | 2 | 5 | 4 | ---------- |
| 1876–80 | ---------- | 3 | | | |
| 1881–85 | ---------- | 6 | 11 | 7 | [4] 7 |
| 1886–90 | ---------- | 8 | | | |
| 1891–95 | 3 | 7 | 10 | 7 | 6 |
| 1896–1900 | 8 | 5 | | | |
| 1901–05 | 13 | 11 | 15 | 9 | 3 |
| 1906–10 | ---------- | [5] 11 | | | |
| 1911–22 | ---------- | ---------- | 14 | 12 | 10 |
| Total | 24 | 53 | 55 | 39 | 26 |

[1] Data by Ashe, W. W., 1905—In Preliminary Report of the Inland Waterways Commission. 60th Cong., 1st sess. S.Doc. 325, p. 522.

[2] Data from Report of Flood Commission, Pittsburgh, Pa., 1911, p. 46.

[3] Data from The Spring Floods of 1922, by H. C. Frankenfield, U.S.Dept. of Agr. Mo. Wea. Rev. Suppl. 22. 1923.

[4] Includes 1880.

[5] Includes the floods during January 1911.

[40] Glenn, L. C. 1911—Denudation and Erosion in the Southern Appalachian Region. U.S.Geol.Sur. Prof. Paper 72.

[41] Leighton, M. O. Floods. U.S.Geol. Survey. Water Supply Paper 234. 1909.

[42] Ashe, W. W. Special Relations of Forests to Rivers in the United States. Preliminary Report of the Inland Waterways Com., 60th Cong., 1st sess., Sen. Doc. 325. 1905.

The causes of this increase in flood frequency, insofar as they arise from human activities, are subject to modification and correction. A solution of the flood problem demands a full recognition of all factors concerned, a determination of methods and objectives, and application of those methods.

## WATER SUPPLY [43]

Only in years of drought, as 1925 and particularly 1930, do the water problems appear in their true and full importance. Rains are usually so well distributed throughout the growing season that precautions or preparations against exceptional droughts are not usually made. The drought of 1925 was severe, but the great 1930 drought caught many communities quite unprepared for the reduced water supplies on which they had to depend. Both in towns and country the pinch of want of water was severe.

A thorough study of ground waters and wells showed that the water table was declining. Dr. W J McGee of the Bureau of Soils found that, over a period of 22 years, records of 9,507 wells (a great many of which are within the Ohio Valley) revealed a lowering of the water table at a minimum mean rate of 1.315 feet per decade, corresponding to an aggregate of 13.8 feet for the 80 years since settlement began. The experience of communities, which have found it necessary to deepen their wells periodically, fully corroborates this trend and indicates that the water table and deep ground supplies are still shrinking.

Water supplies are drawn from ponds, cisterns, surface wells, deep wells, and from open reservoirs. For many cities, water is drawn directly from rivers. For example, Columbus, Ohio, has two reservoirs to supply the city, both located on the Scioto River, one above the other. Nashville, Tenn., draws its supply from the Cumberland River; Cincinnati, Ohio, has a municipally owned plant with water taken from the Kentucky side of the Ohio River; Pittsburgh, Pa., takes its water from the Allegheny River. Other cities in the Ohio Valley also use river water.

The 1930 drought emphasized the inadequacy and shrinking of water supplies in the Ohio River Basin. Stream flow ceased in many cases and only the larger streams continued to flow. Within the Wabash Valley, water supplies were frequently so very low that Bloomington, Batesville, Bloomfield, and a number of other towns in southern Indiana had periods of shortage of varying length during which residents had to haul or ship water from outside points. In rural districts, water, both for livestock and domestic use, had to be hauled over considerable areas at various times beginning in midsummer of 1930. It was estimated in February 1931, that in some southern Indiana counties a fourth of the farmers were hauling water. Not until March 1931, was the shortage in municipal and domestic water supplies relieved. In the Miami, Scioto, and Muskingum Valleys, conditions were likewise severe. In the Muskingum River Valley the normally dependable springs went dry. Within the

---

[43] Data on water supplies in the Ohio River basin, and the effect upon them of recent droughts have been obtained in large part from H. E. Grosbach, U.S.Geol. Survey district engineer, Indianapolis, Ind.; from Roy L. Morton, State sanitary engineer, Nashville, Tenn.; from Effect of the 1930 Drought upon Ohio Public Water Supplies, by F. H. Waring and F. D. Stewart (Ohio State Univ. Eng. Exp. Sta. News, 3 (3), Suppl. 1931); and from Principles of Water Power Development by Dr. W J McGee (Science, N.S. vol. 34 (885)): 813–825. Dec. 15, 1911.

valleys of the Tennessee and Cumberland Rivers, water supplies also were severely diminished. Inadequate ground water failed to maintain the springs; too much of the rain has been running off instead of percolating into the soil.

The quality of waters from open reservoirs and rivers, such as communities use during droughts, is far from satisfactory. Because of the open condition of the supply and its temperature, organic life such as algæ increases tremendously. During 1930, operation of municipal water-supply systems was affected by a condition of the water approaching stagnation. Waring and Stewart state that palatability of the supply for eight cities and villages using water from the Ohio River was impaired, in spite of the fact that sufficient water was in the river to supply the pumps and piping systems. They report that the river became a succession of pools created by the Government navigation dams, and the more or less stagnated water developed obnoxious tastes that could not be entirely removed even by purification. Acids and other industrial wastes became sufficiently concentrated to damage plumbing and fixtures in water systems and households.

Problems of water supply are among the most pressing and important facing the people of the Ohio Valley. Not only are sufficient quantities to meet needs at all times essential, but the water must be pure, potable, tasteless, clear, cool, and reasonably soft to be acceptable.

### EROSION

A third major watershed problem of the Ohio Valley is that of erosion. The loss of soil and soil fertility is a fundamental reason for the decline of communities and their prosperity. Loss of capacity to produce wealth makes land less capable of bearing taxation to support local government. Aside from the decline of soil fertility arising from overcropping and lack of proper care of the soil, the greatest cause of soil deterioration is the washing away of the invaluable top soil.

The entire area of the Ohio Valley is subject to erosive processes. The northern and northwestern portions have been damaged relatively little because of the generally level surface. Other factors being constant, the severity and rapidity of erosion varies closely with degree of slope and the roughness of the topography. The greatest severity of erosion is consequently found in the hilly to mountainous sections where erodible soils have been cleared unwisely.

On the hilly southern portions of the Wabash Basin, destructive erosion has taken place. Fisher [44] emphasizes the occurrence of thousands of acres of eroded lands in southern Indiana which were formerly quite fertile. These areas have been destroyed by loss of soil.

In the watershed of the Raccoon Creek in Ohio, a study of Vinton County [45] revealed that although there is not much gullying, sheet erosion occurs generally over the county, especially on the steeper cultivated slopes. In the Muskingum River Valley, surveys by Dr. G. W. Conrey, of the Ohio Agricultural Experiment Station, have shown

---

[44] Fisher, M. L. The washed lands of Indiana: a preliminary study. Purdue Univ. Agr. Exp. Sta. Cir. 90. 1919.

[45] Sitterly, J. H., Moore, H. R., and Falconer, J. I. Land utilization in a southeastern Ohio county. Ohio Agr. Exp. Sta. Bul. 485. 1931.

in some localities as high as 24 percent of the area severely damaged by gullying alone. In the basin of the Monongahela River, Glenn found less erosion in 1911 than commonly occurs in the Appalachian Mountains farther south, because of the practice of seeding the slopes to grass. On the Green River drainage certain soils have been found to erode very severely,[46] and great damage has followed the clearing and use of these lands for agriculture. When erosion progresses far enough, abandonment follows. On the mountainous lands of the headwaters of the Kentucky River, tremendous erosion [47] was found to follow clearing slopes for crop production. On the Tennessee River, Dr. C. A. Moores, director of the Tennessee Agricultural Experiment Station, reports that washing is very severe, involving serious losses, which have, indeed, occurred over the whole State.

Accepting conditions of watershed as continuing in their present state, King concludes that higher flood stages will be developed in the future, owing to the deposits in stream channels and on river flood plains of material eroded from side hills and steep slopes.

Close estimates have not been made of the amount of land in the Ohio Basin which has been and now is badly damaged by erosion. In this connection, Knight [48] states that between 10 and 15 million acres of the 78 million acres in the Appalachian Mountain area have been seriously eroded and approximately 2 million acres have been permanently ruined for farming by gullying. The total area of badly and seriously eroded land is very large—an immensely important factor in the watershed problems of the Ohio River.

### POWER

Because of the large proportion of the Nation's population and large industrial activities which lie within its borders or adjacent to it, the development and realization of long-lived sources of electric power are of fundamental importance in the Ohio Valley and constitute a major watershed problem in the solution of which local topographic features are favorable. From average State estimates by the Secretary of Agriculture in 1911, it seems probable that in the neighborhood of 2 million horsepower can be generated.[49]

Present hydroelectric installations comprise over 1,220,000 horsepower. Muscle Shoals on the Tennessee River, costing about $127,000,000, is the largest individual plant. Only a portion of the available power in West Virginia, Kentucky, Tennessee, and North Carolina has been harnessed. District Engineer H. E. Grosbach estimates that Indiana normally produces 150,000–160,000 kilowatt-hours yearly from plants run by water power, part of them being in the northern part of the State, and that Kentucky has installations of hydroelectric plants for 145,000 horsepower.

Rates of streamflow are of primary importance to the power industry. When streams are in flood the output is reduced; when streams are low, insufficient water is available to maintain the output. Both extremes of greater floods and lower streamflow work to the disadvan-

---

[46] Soil Survey of Muhlenberg County, Ky. U.S. Dept. Agr. 1924

[47] Craig, R. B. Forestry in the economic life of Knott County, Ky. Ky. Agr. Exp. Sta. Bul. 326. 1932.

[48] Knight, H. G. Soil conservation a major problem of agricultural readjustment. Proc. of Nat. Con. on Land Util. Government Printing Office. 1932.

[49] Sec. of Agri. 1911. Electric Power Development in the U.S. S.Doc. 316, pt. II. 1911, table 2, p. 14.

tage and loss of power generation. In the recent drought, according to Grosbach, production of power on the Wabash River in Indiana had an output of 59 percent normal in 1930 and 72 percent in 1931. According to the same authority, at Lock 7 on the Kentucky River the output during 1930 was 58 percent of the 1929 output and for 1931 80 percent of 1929. At the hydroelectric plant of 3,000 horsepower capacity on the Miami River at Hamilton, Ohio, the output for 1930 was cut down, along with other installations in Ohio, to about 65 percent normal.[50]

Erosion and the burden of debris, as conditions of stream flow, are fundamental in the life of storage reservoirs and their capacity to store water. Although the fact is usually soft pedaled, the erosion, which is taking place is greatly reducing the life and efficiency of storage reservoirs for power-plant uses. Glenn, in the 1911 report already cited, wrote as follows regarding such conditions in the Southern Appalachians:

> From the slopes along these streams a steadily increasing amount of waste is working its way down their channels, filling the dams and destroying their storage capacity; and this loss of storage means a decrease of efficiency that is calculated by the most experienced mill engineers to amount to 30 to 40 percent in plants that have been built especially for storage and a somewhat less marked decrease in other plants, the exact amount depending on the topography of the basin and the regimen of the particular stream on which the plant is located. So universal is this silting of storage basins that a prominent mill engineer of wide experience in his reports on the construction of power plants no longer calculates on power or on anything except the flow of the stream, and he has increased his usual construction estimates by an allowance for increased storm waters that must be taken care of without endangering the dam or plant. Experience has shown that storage basins constructed in this region in recent years are rapidly filled with sand and silt, through which the stream maintains a channel only large enough to carry the ordinary flow.

There can be no denying the fact that conditions of watershed are pertinent to the power producer and consumer alike, because of the costs and life of developments which are involved. In view of the large capital investments, and in view of the permanence of the market for power among the industries and communities of this region, watershed protection is essential in order to effect the longest possible life of the storage capacities of reservoirs, and the greatest efficiency of installations.

## NAVIGATION

The fifth major watershed problem of the Ohio River is that of navigation. The Ohio has greatly changed since settlement in its basin really began on an extensive scale. Its French name, "La Belle Rivière," the beautiful river, depicts its early condition. The Jesuit missionaries that visited the region told of its placid waters that flowed as clear as crystal. Audubon writes of watching the fish in the water as he floated down the river on a raft. The records of those who early journeyed to New Orleans on the white pine rafts from the headwaters of the Allegheny tell of the exceptional clearness and purity of the Ohio. Today the Ohio has a different appearance. It is murky and carries a heavy burden of silt. It is defiled with the mining and industrial wastes and sewage of dozens of cities and towns from its head to the Mississippi.

---

[50] Lee, Lasley, 1931—The Ohio Stream Flow Survey. Ohio State Univ. Eng. Exp. Sta. News Suppl. to vol. 3, no. 3, pp. 54–57, 1931.

Navigation was far more important in the past than today. Not only the Ohio but many smaller tributaries of the Ohio were formerly navigable, at least for portions of their lengths. The first steamboat appeared on the Ohio in 1811. By 1840 there were 1,200 of them plying the waters.[51] Thereafter, largely because of the appearance of the railroad, boat travel declined. By raising the water level through a system of Federal locks, sufficient depth (9 feet or more) is now gained to float boats over the major bars and shoals. A series of 49 dams was completed in 1929 at a cost to the public of over $118,000,000. The annual cost of maintenance is $2,000,000.[52] Some 22,337,000 tons of freight were shipped on the Ohio in 1930, half of which was in the vicinity of and just below Pittsburgh, Pa.

Navigation has fallen off on the Tennessee River also. It is at present interrupted by low flow about 60 per cent of the time and by flood and overflow 1 or 2 percent of the time.[53] In order to restore use of the Tennessee River for water transportation, Congress has recently adopted a new project for this river creating a 9-foot navigable depth from the mouth to Knoxville, a distance of 640 miles, and has authorized an expenditure of about $75,000,000 to accomplish this.

Despite the tremendous investment in water transportation, inadequate or little effort has been made to protect the watershed contributing to the flow of the Ohio and its tributaries to establish a more uniform flow, or to eliminate the silt burden dumped in it continuously from eroding lands by unnecessary and abnormal run-off.

## CAUSES OF WATERSHED PROBLEMS

The causes of increasing floods, inadequate water supplies, destructive erosion, reduced efficiency of power plants, and hindrances to navigation very largely arise from misdirected human activities. Because these disturbances are man made, they are subject to correction and modification. Deforestation and destruction of surface litter is a primary cause of the extremes of stream flow which the communities in this region now experience. Run-off has been greatly increased in times of rainfall with consequent decrease of stream flow in times of drought. Several practices are responsible for these circumstances.

### CLEARING OF NONAGRICULTURAL LAND

The clearing or cultivation of land which erodes badly when cleared is a primary cause of unbalanced stream flow. Many observers have recorded the accelerated run-off and waste of soil which follow the clearing and exposure of mountain lands within this basin. Ashe and Ayres [54] credit land clearing as the most permanently destructive practice used on mountain lands and maintain that much of this land should forever remain in forest, some of the cultivated fields sloping at an angle of 30° to 40°, and some being even too steep for the mountain steer and bull-tongue plow.

---

[51] Switzer, J. E. The completed Ohio River Project. Proc. Indiana Acad. Sci. 41: 339–349. 1932.
[52] Annual Report, Chief of Engineers, U.S. Army. 1929 pts. I and II, 1932, pt. I.
[53] Report from Chief of Engineers on Tennessee River and Tributaries, 71st Cong., 2d sess., H.Doc., pt. (1): 328, 38–41.
[54] Ayres, H. B., and Ashe, W. W. The Southern Appalachian Forests. U.S. Geol. Survey. Prof. Paper 37, 1905.

Glenn points out the immediate gullying of cleared slopes which, even though in grass, wash down to the bare rock. Craig in Kentucky, in the bulletin already cited, notes the use of land for corn fields on slopes as steep as 75 percent, where, because of erosion, the maximum limit of arability is 15 years.

Even in lower country severe soil losses take place. In Hopkins County in western Kentucky, a small reservoir and watershed of 2,340 acres were examined [55] for siltage after 20 years' time. Maximum differences in elevation in the watershed amounted to only 206 feet. The steeper slopes were wooded. Of the 930 acres farmed, 350 were in grass. Silting had taken place, however, at the average rate of 3,534.6 cubic yards a year. The cultivated land was rolling and had only 40 feet difference in elevation; yet the burden of silt, almost entirely from the cultivated lands, amounted to 6 cubic yards per acre per year. This is illustrative of the loss that can and does occur from erosion of gentle or rolling arable lands. It does not adequately portray the soil damage being done on rougher and steeper lands.

Glenn notes that in the process of land clearing in the mountains, the soil frequently has been washed away and the area abandoned before the land is completely cleared of the girdled forest. Adjacent areas are then cleared and the process is repeated. Ayres and Ashe, as already cited, estimated that 24 percent of the Appalachian Mountain area has been cleared. The reclearing of abandoned areas has helped to lower the net total cleared average.

Not only does the land soon wash away when slopes are deforested and exposed, but rainfall runs off down the stream courses in excessive quantity instead of percolating into the soil. Leighton, by his studies (already cited) on the three major branches of the Ohio River above Wheeling, W. Va., clearly proved the increase of run-off and the progressive increase in flood occurrences on a drainage area the deforestation of which had been constant and rapid for 30 years. He states without qualification that—

> the increase in flood tendency * * * is due by far the largest measure to the denudation of forest areas.

Run-off varies in different portions of the basin and is increasing in proportion to the deterioration of the surface conditions. Humphreys and Abbot [56] estimated in 1861 that the proportion of run-off to rain in the Ohio basin is 24 percent. Measurements given in the 1911 report of the Pennsylvania Flood Commission show that for the period 1899–1910 mean annual run-off above Pittsburgh varied from 40.0 to 71.7 percent of the rainfall, and that at Wheeling, W.Va., for 1904–8 it was 58.9 percent. On the Allegheny at Aspinwall, Pa., it was 66.4 for the years 1903–7. Recent measurements in Tennessee reported by King indicate that 45 percent of the precipitation usually runs off into streams of that State, and that in the "cloudburst" causing the 1929 flood, measurements indicate that 91.5 to 97.3 percent of the concentrated rainfall was immediately lost as run-off.

---

[55] Atkinson, J. B. Watershed of Loch Mary. The Bee, Earlington, Hopkins County, Ky., Mar. 11, 1909.

[56] Humphreys and Abbot, The Physics and Hydrology of the Mississippi River, Philadelphia, 1861; see also Fuller, M. L., Underground waters of eastern United States. U.S. Geological Survey. Water Supply Paper 114, 1905.

Loss of soil porosity, a major reason for the accelerated and at times almost complete run-off from cleared lands, is shown by studies[57] in Ohio. These show that the top inch of forest soils absorbs 51 times as much water per minute as does the top inch of adjacent field soils; that the forest soil at a 3-inch depth absorbs water 14 times as fast as do field soils; and that forest soils at an 8-inch depth absorbs water twice as fast as similar field soils. Studies in Mississippi and Wisconsin on the relative volume of run-off from cleared bare soil and from forested land fully substantiate the evidence of greatly increased run-off following removal of forest growth.

### FIRE

Forest fires have greatly deteriorated portions of the Ohio watershed. Uncontrolled fires in the slashings following lumbering, and light burning to encourage the growth of grasses and sprouts, have contributed heavily to the creation of conditions unfavorable to regulated stream flow. Brooks[58] states that the wholesale destruction by fire of the protective softwoods forests and peaty soils began about the time of the Civil War, when an opening was begun by a fire which spread from the camp of Confederate Scouts on the Roaring Plains of Randolph County, W.Va. Prior to 1915 very few records were kept to show the extent of early forest fires in this basin. Prof. C. S. Sargent in volume IX of the tenth census, records the burning of 2,183,393 acres in the States of Indiana, Kentucky, Ohio, Tennessee, and West Virginia during 1880. In 1908, a particularly bad fire year, 3 percent of the estimated standing timber in West Virginia (some 944 million board feet) was destroyed according to the report of the West Virginia Conservation Commission, as quoted by Brooks. Every county in the State was visited by fire, and the total area burned over by the 710 reported fires represented more than 10 percent of the whole surface of the State and 20 percent of its forest area.

The areas of watersheds now damaged by fire are very large. Data compiled by the Forest Service on the areas of land burned over since 1920 are given in table 9 for States lying almost wholly in the Ohio River basin. Inability to subdivide States makes it inadvisable to show areas being damaged by fire for other States. The causes of fire are almost entirely man-made.

TABLE 9.—*Areas of forest burned over, by years and States, Ohio River Basin, 1921–31*

| Year | Indiana | Kentucky | Ohio | Tennessee | West Virginia | Total |
|---|---|---|---|---|---|---|
| | *Acres* | *Acres* | *Acres* | *Acres* | *Acres* | *Acres* |
| 1921 | 2, 275 | 32, 940 | 9, 851 | 30, 437 | 11, 900 | 87, 403 |
| 1922 | 2, 834 | 104, 735 | 17, 215 | 83, 141 | 159, 182 | 367, 107 |
| 1923 | 33, 405 | 287, 421 | 10, 666 | 115, 118 | 189, 916 | 636, 526 |
| 1924 | 32, 093 | 367, 998 | 13, 491 | 224, 944 | 32, 406 | 670, 932 |
| 1925 | 12, 765 | 69, 377 | 19, 479 | 310, 248 | 61, 681 | 473, 550 |
| 1926 | 3, 090 | 41, 040 | 2, 285 | 114, 000 | 50, 763 | 211, 178 |
| 1927 | 9, 000 | 48, 910 | 2, 260 | 84, 590 | 18, 030 | 162, 790 |
| 1928 | 10, 000 | 184, 850 | 13, 600 | 151, 700 | 121, 210 | 481, 360 |
| 1929 | 18, 350 | 154, 150 | 5, 830 | 78, 610 | 41, 170 | 298, 110 |
| 1930 | 200, 000 | 755, 720 | 30, 710 | 859, 490 | 353, 400 | 2, 199, 320 |
| 1931 | 146, 000 | 718, 450 | 16, 090 | 674, 400 | 136, 530 | 1, 691, 470 |

[57] Auten, J. T. Porosity and Water Absorption of Forest Soils. In press for Journal of Agricultural Research, U.S.Dept.Agr., 1933.
[58] Brooks A. B. Forestry and Wood Industries. W.Va. Geol. Survey. 5 : 51, 52, 1911.

The greatest damage by fire to the Ohio watershed is the loss of the forest litter, consisting of leaves, needles, twigs, moss, peat, decaying wood, and other vegetative parts. This forest litter acts as a protective soil covering, and is essential in maintaining the porosity of soil and the preservation of channels and minute holes in the topsoil from the pounding action of falling rain. The destruction of litter by fire removes this protection and partially exposes the soil. Furthermore, the heat of fire damages the loose, granular, porous structure of topsoil, by destroying the organic and inorganic colloids which are so important in maintaining this porous flaky condition.

Very hot fires may burn the forest trees themselves, completely killing them, but this is less serious, in terms of watershed control, than is the loss of litter in every type of fire. The hardwoods tend to renew themselves after fire by sprouting, but repeated burning often prevents more than a brush cover, which while undoubtedly helpful in holding the soil is probably much less effective than the high forest in building up the soil and in preserving favorable conditions of water flow. In the spruce forests at high altitudes particularly, fires have been very destructive. Here the soil is shallow, in places scarcely more than deep duff of undecayed litter. Where this has been burned, the soil itself is practically destroyed. Studies by the Appalachian Forest Experiment Station in West Virginia on the Shavers Fork burn of 1924 indicated that from 12 to 18 inches of spruce and hardwood litter and detritus accumulation was destroyed by fire. On such areas vegetation is slow to return.

Efforts to control fire took form first in West Virginia in 1908. In Ohio, organized fire protection began about 1921 for the southern forest zone; for southern Indiana, about 1930. Efforts to effect fire control in Kentucky and Tennessee have been inadequate, and protection on federally controlled areas has begun only as the first units were established. Far better and more adequate fire protection is needed throughout the forested portions of this basin, in addition to the excellent work done heretofore. With more adequate fire protection, watershed conditions in this basin should rapidly improve insofar as fire is concerned.

### GRAZING

The influence on stream flow which grazing exerts in the Ohio River watershed consists of the effect which domestic animals have on woods and soils conditions. Confining stock to small areas of forest results in destruction of forest litter from continual and repeated trampling and cutting by sharp hoofs. The porous condition of the forest soil is then quickly destroyed, not only by the loss of forest litter, but by the heavy weight of the animals themselves. By repeated trampling and moving around, the soil is compacted and firmed until it is impervious except to very slow rainfall. Further damage includes the loss of undergrowth and seedlings which the livestock consume and the barking and trampling of tree roots.

The greatest influence of grazing is found in the agricultural regions where large numbers of livestock are raised, and are confined on small areas. Within the rougher, more wooded portions of the basin, grazing is a minor factor; but in the agricultural localities it is a very important one. Later reference will be made to grazing.

### LUMBERING

The removal of the forest by logging has been a very disturbing factor in the Ohio River drainage. But the harvesting of virgin timber in itself has not been as disastrous to the conditions of stream flow as have been the elements of repeated fires and the clearing of nonagricultural land, especially in the rougher portions of the basin.

In the smoother portions of the basin, on the Wabash, Miami, and Scioto Rivers and in the Karst, Bluegrass, and Central Basin regions of Kentucky and Tennessee, cutting was originally done to clear land for raising crops. Available records [59] show that the forest area of Ohio declined from almost 14 million acres in 1853 to less than 5 million acres by 1880. Similarly, in Indiana, forests were reduced by 3 million acres in the decade 1870–80.[60] In the rough eastern portions of the basin, clearing occurred later. Leighton, already cited, implies that rapid deforestation was occurring on the Allegheny and Monongahela Basins from 1875 to 1907. In the rough Cumberland and Allegheny Mountains cutting and culling of the forest waited upon but closely followed development of railroads.

Since 1900 lumber companies have been rapidly cutting over the remaining forests in the rougher sections of the Ohio Basin. The peak of lumbering in the Ohio River Basin was reached about 1899--1910, with a cut of some 5 billion feet, and has since fallen to the 1869 level of about 2 billion feet in 1929. There is very close agreement between the advance of lumbering, the period of repeated uncontrolled fires, the increase in run-off, and the increase in number of flood crests, save that the damage done to watersheds has rather increased than otherwise with the decrease in lumbering.

### DIVISION OF LAND USE

For purposes of this report, the Ohio Basin is found to classify broadly into (1) the level agricultural land, which, because of soil fertility and ease of cultivation, has the ability, when intelligently handled, to stand up under the demands of agricultural use; (2) the forest land, which because of its rough, steep, and broken surface is unstable and subject to erosion when cleared. Broadly speaking, this division follows the line of glaciation.

North of the Ohio River, the level to gently rolling plain is a result of several advances of the ice sheets. In the balance of the basin the land is in the process of eroding down to a more level surface. In general, the glaciated section is farm land, and the major part of the rest of the basin is too steep or erodible to bear cultivation. Within the unglaciated regions there are such provinces as the Karst, Bluegrass, Appalachian Valley, and Central Basins of Kentucky and Tennessee which are agricultural. In this report they are considered with the farm lands north of the Ohio River.

### FARM LANDS

Fire is not a serious problem on farm land because of the separation of remnant woods by the large cultivated areas. Most farm woods are seriously overcut and overgrazed and these are the major destruc-

[59] First Annual Report—Ohio State Bureau of Forestry, Columbus, Ohio, 1886.
[60] Pegg, E. C., and Thomas, M. B. The Woodlot for Central Indiana. Proc. Ind. Acad. Sci. 18:419–440, 1910.

tive agencies. In their present limited extent they can be classified as having slight or at best only moderate influence on watershed problems within the glaciated province, and moderate influence on the agricultural lands to the south and in the Appalachian Valley. (See fig. 9 for relative influence of forests on watersheds.)

Under constant grazing, these woodlots have steadily deteriorated until the forest has become merely open parks, open-air pens, or feed lots. Under such a condition the forest is of little value from a watershed standpoint, and there is reason to anticipate the destruction of the woodlots themselves.

Auten's work, already cited, in the Central States Forest Experiment Station's study of soil conditions in grazed and ungrazed woods in Ohio, showed that for 36 plots, the top 9 inches of soil in the grazed area averaged 15 percent heavier than similar top soil from ungrazed woods. This increase in density is a reflection of the greatly reduced capacity of the grazed soils to absorb water.

In Ohio, the survey of deep-well supplies following the 1930 drought, by Waring and Stewart (already cited in the discussion of "Water Supply"), revealed that, instead of being replenished by fall and winter precipitation, the water level of the deep ground-water supplies was either stationary or slowly receding. Obviously, water is not getting into the soil in adequate quantities. Whether through loss of forest cover and forest soil porosity, or through tiling and open drainage ditches which drain off rainfall immediately, the effect of lowered water table is the same.

The problems of run-off and erosion in the farming section are agricultural problems and as such farm practice is responsible for them. The judicious treatment of farm lands can very largely meet the demands of watershed considerations in so far as they concern farming sections. Owners of valuable farms can, by the best farm practices, maintain their lands in a continuously productive state. Intelligence and concern are essential to careful handling of these lands.

## FOREST LANDS

The original forest exerted a very great influence on the streams and rivers which had their source in the high Allegheny and Cumberland Plateaus and the Southern Appalachian Mountains. An estimate of the influence of forests on stream flow in this basin, as shown in figure 9, is given in terms of area in the following tabulation:

| | *Acres* |
|---|---|
| Total area of Ohio River Basin | 130, 420, 480 |
| Total forest area | 45, 391, 000 |
| Forest area of great influence | 35, 919, 000 |
| Forest area of moderate influence | 7, 569, 000 |
| Forest area of slight influence | 1, 903, 000 |

## OWNERSHIP OF FOREST LAND

By far the largest portion of forest lands in the Ohio basin is in private ownership. In the aggregate, small owners control a large area of forest, but there are also many large holdings, as coal, gas, and oil corporations, as well as a few lumber companies. This private ownership is unfavorable to conservative handling of these lands.

The need for protection and management of watershed land at the headwaters of the Ohio has been recognized by the Federal purchase

of certain lands in this basin. The Allegheny National Forest is on the headwaters of the Allegheny River, a portion of the Monongahela National Forest occurs on headwaters of the river of that name, parts of the Unaka, Cherokee, Nantahala, Pisgah, and Alabama National Forests are on portions of the headwaters of the Tennessee River, and a portion of the Unaka National Forest takes in headwaters of the New River. Because the present extent of these lands (about 2,400 square miles) is too limited to be most effective, the Forest Service plans to add to them. Plans have also been approved by the National Forest Reservation Commission for a national forest purchase unit on the headwaters of the Kentucky River.

Some States in the Ohio basin are also engaged in programs of forest-land acquisition. Reference to the section of this report on "State Accomplishments and Plans" will yield in tabular form the acreages of State forests in Indiana, Ohio, Kentucky, and West Virginia.

A few progressive communities are protecting reservoir sites and watersheds by forests. For example, Akron, Ohio, has 5,000 acres in a municipal forest. Wellston, Ohio, has a 300-acre watershed above its storage reservoir. Denuded lands on this area have been planted. Other Ohio cities having municipal forests include Oberlin and Cincinnati. The Mahoning Valley Sanitary District, which supplies water to Niles, Youngstown, and Girard, possesses 4,500 acres.

### MARGINAL FARM LAND

A necessary step in the solution of watershed problems for the Ohio River is the removal of submarginal and marginal land from the status of farm land. Such land is not agricultural at the outset because of many considerations, and continued use aggravates the problems of watershed as well as of agriculture. For example, Sitterley's study (already mentioned) in the southeastern section of Ohio shows a shrinkage in improved lands in farms from 56 percent in 1900 to 26 percent in 1930. The number of farms has decreased 51 percent in 30 years. The population of Vinton County in this region shows a decline of 40 percent. A similar study in another county found a decrease of 20 percent in the acreage of land in farms since 1880 and a decrease of 50 percent in the improved land in farms since 1900. Only 15.7 percent of the total area of the county was in harvested crops in 1929.[61]

It is evident that these areas of land are unable to support an agricultural system, its population, and local government. These studies are illustrative of about 14 counties in this vicinity, in which a million acres of land are lying idle outside of farms and half a million acres within the boundaries of farms. Much of the badly eroded farm land has been abandoned to revert to forest. As high as 50 percent of certain counties in southern Ohio might well be in forest. The use of much marginal land for pasturing seems unlikely. A specialist in crops and soils[62] at Ohio State University states, "Between 55 and 60 percent of the now so-called permanent pastures in Ohio * * * should be returned to forests as the cost of liming and fertilizing makes pasture production prohibitive."

---

[61] Sitterley, J. H., Moore, H. R., Falconer, J. I. Land Utilization in Lawrence County, Ohio. Ohio Agr. Expt. Sta. Bul. 514. 1932.
[62] Bailey, M. V., Permanent Pastures. Ohio State Univ. Agr. Ext. Service Bul. 61.

A study of Laurel County, Ky.,[63] by the Division of Land Economics, United States Department of Agriculture, and the University of Kentucky, led to the conclusion that cropping land for corn on steep slopes results in rapid erosion and early abandonment; that the cycle of subsequent reclearing and recultivation leads to decline in soil and economic returns to the point where returns are less than direct costs; that this is the condition on 25 percent of the crop land at the present time; that on an additional 19 percent soil "mining" was necessary to cover costs; and that 4 out of every 10 acres of crop land are losing money.

In his similar study in Knott County, Craig found that all the better agricultural land on these slopes has been made nonarable through erosion.

A recent study in West Virginia[64] found that 85 percent of the locally raised taxes were absorbed by schools and roads, and that "although the maximum rates permitted by law have been levied for most purposes, deficits are common, particularly in the general county and the various school levies. The deficits are becoming more frequent on account of the declining value of agricultural, coal, and timber lands." Another West Virginia investigation[65] pointed out that the prosperity and well-being of farmers is closely related to the soil type and topography of their farms.

It is thus shown that a considerable part of the problem of the agricultural lands is also a problem, and an important one, of the forestry problem on watershed lands. The seriousness of the situation is too great to be ignored, and the area is far too large to be left to take care of itself. The social phases no less than the strictly economic phases require thoughtful consideration. Since conditions of stream flow have been unbalanced by the removal and the deterioration of the forest, they may be improved by reestablishing the forest on denuded lands and by building up the forest where it has deteriorated.

## SUMMARY

The problems of watershed are among the most important ones which confront the communities of the Ohio Valley. Floods causing yearly damage of about $4,600,000 and as high as $180,000,000 are on the increase; domestic water supplies are inadequate and too frequently drawn from questionable sources. Erosion is destroying or else robbing the producing capacity of millions of acres of the soils, especially those which have been exposed injudiciously. Hydroelectric power of some 2 million horsepower has immense potentialities, the full realization of which depends on the regulation of stream flow and the elimination of a heavy burden of debris and soil wash. The maintenance of navigation is being heavily subsidized at public cost with inadequate attention to the watershed concerned. Over the last 11 years, about 15,738,000 tons of freight have been shipped annually on the Ohio River alone, whereas in 1930 all shipments by water were some 22,337,000 tons.

---

[63] Clayton, C. F., and Nicholls, W. D., Land Utilization in Laurel County, Ky. U.S.Dept.Agr. Tech. Bul. 289. 1932.

[64] Peck, M., Frank, B., and Eke, P. A., Economic Utilization of Marginal Lands in Nicholas and Webster Counties, W.Va. U.S.Dept.Agr.Tech.Bul. 303. 1932.

[65] Phillips, S. W. 1925—Soil Survey of Nicholas County, West Virginia, U.S.Dept.Agr.Bur. Soils Field Operations. 1920. Rpt. 22. 39–59 illus.

The irregularity of stream flow is directly increased by man-made causes. The increase in run-off and period of low stream flow has been caused by deforestation, in clearing large areas of nonagricultural land, by uncontrolled forest fires, by grazing, and by unregulated cutting with no care for the future. Since 1921 over 660,000 acres have been burned over annually. The forests of this basin have been so depleted that production of lumber has declined from 5 billion feet in 1899–1910 to 2 billion feet in 1929.

In the agricultural sections of the basin, the solution of these problems is to be found in using better agricultural practices and in the elimination of harmful grazing from wood lots. Fire is a small factor. On the forest lands, the permanent regulation of streams demands a rebuilding and improvement of the forest through the elimination of fire, harmful grazing, and unregulated lumbering. The extension of organized fire protection to the entire area needing protection with higher standards and better organization is essential. The return of forests to 4 million acres of land of nonagricultural character must be accomplished in part by planting. Because private initiative is incapable or unwilling to attempt these measures, a vigorous policy of public acquisition of cut-over, abandoned, and marginal land amounting to 28.6 million acres is essential. Of this, probably 6 million acres will be in abandoned farms, and 22.6 million acres will be forest land. Most of this latter area is located in the higher and rougher portions of the drainage and including the mountainous sections at the headwaters. Only through good protection and management of these forests can favorable conditions of water flow be restored. Part of this public ownership must be Federal, because of differences between States in wealth and ability to meet the task. An enlarged program of public education through extension under active leadership and with full participation by all agencies is highly desirable.

Ashe writes (op. cit.):

> The work of the engineer to protect the large river becomes useless unless it is protected by the forest. In the Appalachians * * * and indeed wherever forest influences are high, the river engineer and the forester must work hand in hand.

## MISSOURI RIVER BASIN

The total drainage area of the Missouri River is about 525,000 square miles, including all or parts of 10 States and some 13,000 square miles in Canada (fig. 10). Of the 28,642,000 acres of forest, some 20,515,000 acres is classed as having a major influence and 6,769,000 acres a moderate influence upon watershed conditions. The remainder is rated as exerting comparatively slight influence.

Topographically the Missouri Basin is most varied. About one twelfth of the surface is mountainous, one sixth plains, and the remainder rolling. Because conditions vary so widely, the drainage is considered as in two parts, the upper Missouri, or semi-arid section to the west, and the lower Missouri, or humid sections to the east. The dividing line between these approximates the one hundredth meridian.

### UPPER MISSOURI RIVER

The headwaters of the upper Missouri River lie in the Rocky Mountains, a region of rugged topography. The mountain area consists principally of a strip of high mountains, varying in width from

10 to 100 miles, along the western edge of the basin. Along the Continental Divide the mountains are broken and exceedingly steep. Crests and peaks, and in some localities high rolling plateaus, at elevations of 9,000 to 11,000 feet or more, rise above narrow valleys of 5,000 to 6,000 feet elevation. Within the Plains region, many miles

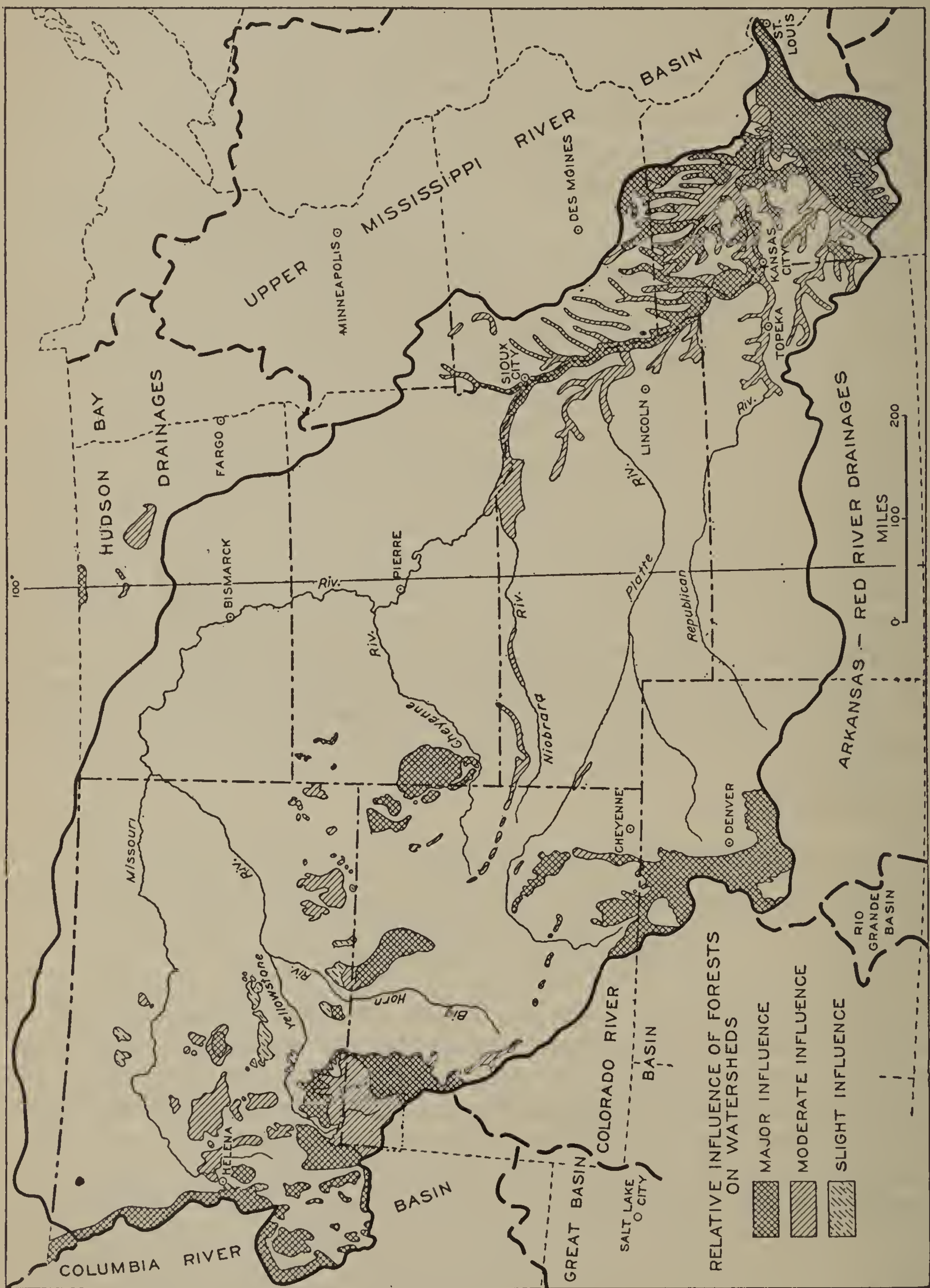


FIGURE 10.—Missouri River Basin and Hudson Bay drainages.

from the Rockies proper, are a number of forested outposts, of which the Black Hills of South Dakota are an example. In portions of the plains are scattered areas of Badlands and of sand hills.

The soils are usually loams varying from gravelly phases in the mountains to heavy clay loams elsewhere.

The precipitation varies from 10 or 12 inches in the semiarid plains of the Big Horn and Milk River Valleys to 50 inches or more in

the mountains. On the average, the precipitation in the forested regions probably reaches 30 inches. Most of this comes in the form of winter snows. Wide variations in the precipitation occur from year to year and from season to season, variations of 50 percent of the normal being not uncommon.

The thaws are mainly responsible for local floods. Very appreciable differences in run-off occur from year to year, due as much to variations in rate of thawing as to the depth of the snow. As indicated in the introductory statement to this section, the rate of snow melt is affected by the condition and character of the cover, and hence the spring flood flows.

The floods in this upper basin usually have little relation to those in the Mississippi, since by the time the high water reaches the Mississippi, the main floods of that river have already passed on to the sea. They are important locally, however, primarily because of their effect on sustained stream flow. Excessive spring floods affect adversely the summer flow. The agriculture of a very large part of the upper plains region is dependent upon stream flow from the forested areas. In some years, practically all the summer flow is taken for agricultural use. The forested area provides all or practically all the water used by such cities as Denver, Cheyenne, and Rapid City. Any condition that adversely affects sustained stream flow from this area, therefore, reacts to the detriment of regional welfare and prosperity.

Ordinarily the streams in the high mountain area are clear, fed by thousands of forest springs and flowing through numerous lakes. They become muddy or silt-laden only during the period of heavy run-off. Streams rising in the more impoverished soils of the woodland areas are usually not clear, except those coming from high plateaus.

### FOREST COVER

The forest belt stretches along the mountain slopes at the western edge of the basin, and takes in the mountain outposts. Although the forest belt includes about 6½ percent of the area of the upper basin, about a third of it is nonforested lands—largely range lands, such as meadows, parks, and grassland plateaus.

The higher elevations are taken by spruce forests, usually dense and maintaining a heavy litter cover. On steep slopes, the forest may be open, but where soil exists, minor vegetation covers the ground.

The lodgepole pine forest is usually fairly dense. Where the lodgepole gives way to ponderosa pine, the forest usually becomes more open.

Ponderosa pine is the principal species of the mountain outposts and sand hills. Owing to the lower precipitation of the plains region, the trees are often of low stature and the forest open but a good ground cover is found where grazing, fire, and cutting have not been too heavy.

The brushy or woodland forest seldom forms a complete cover, reflecting the semiarid conditions under which it has developed.

### PRESENT CONDITION OF THE FOREST

For the most part, the forest cover of today is relatively little different from that which existed prior to the advent of the white man.

Early uncontrolled fires did much damage, especially in portions of Wyoming and Colorado. In the pine regions, restocking has taken place. In the spruce type, the devastation caused by some of the early fires has been so complete that after 50 or more years a forest cover is still lacking on many of the burned areas.

Overgrazing probably has caused greater change in the cover conditions of the upper Missouri than any other factor. Large herds, especially in the woodland areas, have so depleted the forest ranges that only a scanty ground cover is found where formerly a more or less complete carpet occurred. Overgrazing still continues in many places.

Timber cutting, particularly about mining and agricultural settlements, has often been most severe in those places where conditions were least favorable for regrowth. As a result, the forest cover on some areas has been badly depleted.

In a few localities where smelters have operated, such as at Butte, Mont., the cover on nearby slopes has largely been destroyed by fumes. In such places the top soil has washed away, leaving an erosion pavement of rock fragments on the surface.

## OWNERSHIP OF FOREST LANDS

Private forest lands play a very small part in the water or soil conditions of the upper Missouri Basin. They are mostly in small units, scattered throughout the forested region, more of them in the Badlands than elsewhere. Intermingled with the national forest lands, as many of them are, they receive protection from fire. Few are so accessibly located as to be merchantable and consequently their condition is for the most part about the same as that of the national forests. Where cutting has taken place it usually is too heavy, and where grazed, overgrazing is common. Those in the Badlands have suffered particularly from overgrazing. There is a small area of State or other local public lands in the upper basin. Much of this area is in need of better care. The much larger area of public lands is in Federal ownership or control. These are included in the national forests, nation parks, Indian lands, and public domain.

## NATIONAL FORESTS

Of the public lands, the national forests are the most important because of the area of approximately 9 million acres involved, and because of their location at the very headwaters of the river. All forms of use, such as cutting and grazing, are so handled that the watershed cover is maintained in an effective condition. On some of the national forests, where serious overgrazing took place before the areas were put under administration, watershed conditions are not yet entirely satisfactory, but the cover is gradually improving under regulated use.

Fire is not a serious factor. In occasional bad fire years control is difficult, but with the extension of transportation improvement and with more and better equipment there is much less danger of disaster than formerly.

On the whole, the watershed conditions on the national forests are satisfactory and are steadily becoming better.

### NATIONAL PARKS

Some 300,000 acres of national park areas located in this basin—the Rocky Mountain, the Yellowstone, and the Glacier—are involved. Under the park policy of excluding commercial use, watershed conditions are being maintained. Cover conditions, which even before the establishment of the parks were not seriously disturbed, are improving.

### INDIAN LANDS

There is something over a million acres of forest lands in Indian reservations in this drainage. These are subjected to cutting and to grazing. Past missuse on some of these lands has caused deterioration of the cover. The stands have been cut too heavily, fires have been common, and some overgrazing has taken place. In recent years there has been considerable improvement in the cover due to better fire control and to cutting restrictions. More recently, efforts have been made to institute a type of range management similar to that in effect on the national forests. Although this management has not been in effect long enough to bring about marked changes in depleted ranges, it is to be expected as time passes that watershed conditions will gradually improve.

### PUBLIC DOMAIN

Federal lands in the unreserved public domain are in less fortunate circumstances because they are not given as much care and attention as is accorded other public lands. Many of these are in small tracts so scattered that management is difficult. Efforts at fire control and range and forest management on the unreserved public domain have been made, but in the absence of an organization whose specific duty it is to cope with the problem, the situation is not satisfactory. On the whole, much of the cover, particularly the minor vegetation, has been seriously depleted with attendant increased surface run-off and erosion. This is particularly marked in the Badlands.

### BADLANDS

"Badlands" is the name given to rough lands in the plains region, mostly in Montana and in the Dakotas. Something over 10 million acres are involved. Although not covered with a commercial forest, most of the Badlands support a brush and low woodland cover that, if adequately maintained, would probably be highly effective in watershed protection. Some support only a sparse vegetation of brush, and some only grass or other minor vegetation. Woodland is characteristic of the north-facing slopes, and grass of those to the south.

Many of the Badlands soils are silty loams which, lacking a binding material, virtually melt in the rain. Although much of the eroded material is so fine as to be carried to the Gulf, a part of it is deposited in the lower part of the Missouri and Mississippi Rivers. Because of the area involved, the extent of the erosion, and the ease with which erosion takes place, this situation is the most critical one in the upper Missouri, and calls for early remedial action. Of the 413 million cubic yards of soil estimated by the War Department as the amount annually carried by the Missouri River into the Mississippi, probably more than half comes from this section.

Most of the Badlands area is grazed and much of it too heavily grazed for the cover to maintain itself. Where grazing is heavy, erosion is greatly accelerated. Even under light grazing use, many of the steep, unstable clay slopes erode excessively. The soils involved, the paucity of precipitation, the alkaline character of the soil, and the character of cover make good management imperative in the interests of watershed protection. Even with good management, it is doubtful whether erosion can be wholly prevented by vegetation alone. Probably some special measures of erosion control will be necessary. The fact that a very large part of this area is public domain serves to emphasize the fact that public ownership alone is not sufficient to insure good watershed conditions.

## LOWER MISSOURI RIVER

### GENERAL DESCRIPTION

The more humid part of the Missouri River drainage is essentially a prairie region well suited to agriculture. About 4 million acres of commercial forest land is included in this region. This forest is in the form of stringers which follow the streams far into the prairie region, of scattered woodlands in farming communities, and of more extensive forest areas on the rougher lands. A scrubby woodland type of about a million acres is found towards the western extension of the forest in southwestern Missouri and eastern Kansas and Nebraska. The topography is level to gently rolling. Rough lands occur only in the Ozark region of southern Missouri. In northern Missouri and southern Iowa the terrain is more rolling than on the west side of the river.

The precipitation varies from 20 inches in the plains section to 45 inches in southern Missouri. Most of its comes as rain and the greater proportion in the spring and late summer. During the flood years of 1915, 1922, and 1927, spring storms brought between 20 and 30 inches of rain to the Ozark region and the resulting local floods were a material factor in the flood stages of the lower Mississippi. Torrential rains frequently occur. The Weather Bureau reports a rainfall of 6.61 inches in 24 hours at Columbia, Mo., and a fall of 3 inches in 30 minutes at Fayette. Such rains are unusual, but numerous rains have occurred in which more than 2 inches has fallen in 24 hours. Heavy rains result in a high run off particularly from deforested or burned land.

The Ozark streams contribute markedly to the floods of the Mississippi River. Records of the Mississippi River Flood Commission show that of the Mississippi River flow of 1,850,000 second-feet at Cairo on February 6, 1915, the Missouri River contributed about 200,000 second-feet, or 11 percent, of which 150,000 second-feet or about 8 percent of the Mississippi flow at Cairo came from the Osage River, which drains southwestern Missouri. On April 24, 1922, the Missouri River contributed 460,000 second-feet of a total of 1,550,000 second-feet; of this the Osage accounted for 30 percent, or 9 percent of the flow past Cairo. On April 20, 1927, when the highest flood peak of the year at Cairo occurred, the Missouri contributed 20 percent and the Osage 6 percent of the flow of the Mississippi.

The streams of this area also contribute heavily to the silt load of the river. Thus, on the basis of data from the University of Mis-

souri, the Grand River, which drains part of southern Iowa and northern Missouri, furnishes to the Missouri River some 8½ million tons of soil annually. This is about 5 percent of its silt load. The Grand River drainage is but 1.2 percent of the Missouri River Basin. Because of the large contribution of the lower Missouri region to the floods and silt burden of the Mississippi, most of the forest area is classed as having a major influence upon watershed conditions.

### FOREST

Most of the forest area is in southern Missouri, of which about 90 percent is privately owned, largely in the hands of farmers. The present condition of the forest, therefore, is largely the result of the use which the farm owner has made of the woods. Only in the more inaccessible areas are there large ownerships.

The forests are chiefly oak, though scattered pine is found in the higher elevations and sandier soils. Timber cutting is typically a culling in which the best trees are taken. Fires usually follow, often purposely set to freshen the grass and to obtain more sprout growth for the cattle. Where fires have occurred repeatedly, they have prevented the extension of pine and caused the development of a low coppice forest. This has been further deteriorated through heavy grazing. Brushy, open, and understocked stands occupy about one fourth of the forest area.

At present there is no organized protection for the forest lands of Missouri. Fire control, where it exists, is strictly a local or private matter. Elsewhere, there is general indifference to protection needs. The result is repeated fires, which render impossible the maintenance of a good litter cover or the development of good watershed conditions.

As described in the introductory statement, studies in oak stands in eastern Oklahoma under conditions which greatly resemble the Ozarks show that surface fires markedly increase surface run-off and erosion. Wisconsin investigations have shown that open and heavily pastured forests do not hold back surface run-off much, if any better, than open land and that grass land is responsible for a high percentage of run-off. Undoubtedly some of the very large contributions this area makes to the floods in the lower Mississippi are due to the recurrent fires and heavy grazing.

In the Ozark region, most of the agricultural development has been on the broad ridges and in the bottoms. The 1930 census data show an increase in the area of crop land in a number of Ozark counties. The new areas are largely on the hillsides where continued agricultural use is doubtful because such lands erode rapidly. It is decidedly questionable whether the public should permit land clearing of hill lands in view of the fact that the resulting erosion is so quickly poured into the Mississippi River. More and more agriculturists and soil specialists are coming to believe that hill lands with slopes greater than about 15 percent should not be cleared.

The question of how these practices—use of fire, heavy cutting, pasturage of restocking and steep lands, and the clearing of hill lands for cultivation—can be controlled is an open one. Certainly some positive steps appear desirable. If public restrictions upon private use are not in order, then public ownership is the only alternative.

The heavy contribution the Ozark region makes to the Mississippi floods indicates that a part at least of the Ozark area should be in public rather than in private hands. The situation is more largely one of Federal than of local interest, and the values at stake are too high to permit continued malpractice to threaten extensive public works and the safety of a large population. About 150,000 acres of abandoned farms and denuded lands need reforestation. Special control measures are necessary on about 50,000 acres.

### ABANDONED AGRICULTURAL LANDS IN THE UPLAND LOAMS

The agricultural lands of the upland silt loams have reached a critical stage. Clean cultivation, largely for corn, has resulted in erosion so serious as to make a large area of formerly prairie land of doubtful agricultural value. Much of this area is drained by the Grand River. According to H. H. Bennett of the Bureau of Chemistry and Soils:

> Under continuous cropping to corn the rich top soil (Shelby silt loam of northern Missouri) has been swept away from innumerable areas by erosion, down to a yellow clay subsoil, within a period of about 50 to 60 years on 4 percent slopes, and in about 10 to 20 years on 8 percent slopes. The exposed stiff, yellow clay produces little grass of any value and only about 20 bushels of corn per acre (no corn in dry years) as against more than 50 bushels for the best years on the less severely washed soil. The vegetative changes resulting from erosion on this extensive prairie soil have been most violent, a change from almost exclusive stands of bluegrass, in density of 100 percent ground cover, to scattering weeds and dwarfed grasses of very low grazing value.

At the Bethany (Mo.) Soil Erosion Station, the water loss from an 8 percent slope in corn during 1931 was 30 percent of the total precipitation and the soil loss 84 tons per acre. The corresponding losses from a similar area planted to alfalfa were 0.36 percent of the precipitation and 2 tons of soil per acre. Since forest has been shown by the investigations of the Lake States Station to be more effective than grass or hay cover crops in controlling run-off and erosion, it can be readily realized that forestation on at least some of these badly eroding lands would help to control flood flows and erosion. As forests originally existed on about 40 percent of the abandoned farm land area in southern Iowa and northern Missouri, it is not, therefore, a question so much of putting forest where it has not previously grown, as in restoring it. In 1919 the Iowa Agricultural Experiment Station said:

> Much of the rolling and rough land in southern Iowa that is subject to erosion, especially that near the rivers, was originally in timber and should probably be reforested or seeded down to grass. If this were done little erosion would ever occur.[66]

Recent data from the University of Missouri indicate that 6 million acres of agricultural lands in Missouri are seriously eroding, with gullies 6 to 10 feet deep not uncommon. Dr. M. F. Miller and Dr. C. Hammer of the university estimate that some 2,250,000 acres of these eroding lands need forest planting. Based on an incomplete survey of the whole State, the Iowa State Soil Survey now in progress is revealing that between 2 and 3 million acres of eroding land in Iowa should be permanently taken out of cultivation and planted to trees. The Nebraska Agricultural Experiment Station estimates that more

[66] Eastman, E. E., and Glass, J. S. Soil Erosion in Iowa. Iowa Agric. Exp. Sta. Bull. 183, 1919.

than 8 percent of the farm land in eastern Nebraska is seriously eroded.

Altogether there are about 10 million acres of once fine agricultural land in the lower Missouri drainage which now are of doubtful agricultural value. Because of their relationship to the flood problem of the Mississippi, they are of national significance. Early action should be taken to place this land under some form of management that will prevent further erosion and greater flood losses. For some of the abandoned land that is at least of doubtful value for agriculture, forestry offers a solution. On these lands, it should be possible within a few years to control surface run-off and erosion through planting and other forestry practices.

Conditions are now so serious that it seems scarcely possible for private initiative to correct them. Public ownership of a large area appears to be the only real solution.

## GENERAL CONSIDERATIONS

It has been pointed out that where forest lands in the upper Missouri Basin are given management, satisfactory conditions of stream flow obtain, and that on most lands not administered or managed, watershed conditions are not satisfactory. Public lands under close supervision are in the best shape, and some private lands in the worst. The unreserved public domain approaches very closely the worst of the private lands. This is especially marked in the Badlands where grazing is principally at fault. Here in addition to range management, forest planting, reseeding, and the use of erosion control devices are needed to prevent further soil and water losses. Investigations are particularly essential to determine how far these need to be applied and their proper place.

In the lower Missouri, conditions on the commercial forest lands are very unsatisfactory, especially in view of the far-reaching effect of the run-off from the Ozark highlands. Fires are widespread and there is no organized protection against them. Cutting is done without regard to the watershed conditions. Overgrazing in pastures hastens run-off and increases the flood troubles of the Mississippi. Land clearing on steep slopes has gone too far. Private ownership has given little thought to stream-flow conditions. Whether private enterprise will take any specific action is doubtful. Public acquisition appears necessary on about 7.6 million acres. In this area, the National Government is primarily concerned because of the contribution this area makes to the Mississippi River floods.

On the agricultural silt loam uplands within the prairie region, erosion has reached a stage where land is rapidly going out of agriculture. About 10 million acres of these lands are so eroded and impoverished as to be of doubtful agricultural value. Some of them could support a forest of a kind if planted. Public ownership of a large part of these lands is apparently necessary, but the question of ownership as well as that of future use is one that cannot be determined in the light of present knowledge. If erosion is to be controlled and better conditions of stream flow developed, some combination of forestry with other use is necessary. Thorough investigations of conditions and of the measure needed to restore watershed conditions are necessary.

## ARKANSAS AND RED RIVER DRAINAGES

The Arkansas River heads in the Rocky Mountains of southern Colorado and northern New Mexico, and after flowing through the plains passes through the mountains in Arkansas to reach the Mississippi. The Red River rises in the foothills of the Rockies in west Texas, flows through the Red Plains, skirts the southern edge of the mountains in Arkansas, and empties into the Mississippi River in central Louisiana. The region drained by these rivers is shown in figure 6, which indicates also the location of the forests in these drainages and their relative influence upon watershed conditions. Of the total forest area of 52,220,000 acres 34,560,000 acres, or 66 percent, is classed as having a major influence upon watershed conditions, 15,525,000 acres, or 30 percent, as having a moderate influence, and only 2,135,000 acres, or 4 percent, as having little or no influence.

### FLOODS AND EROSION

The Arkansas and Red River drainages contribute proportionally more to the floods of the Mississippi River than any other section of the great Mississippi Basin. The greater part of this contribution has its source in the Ouachita-Ozark Mountain area of southern Missouri, Arkansas, and eastern Oklahoma; records of the Mississippi River Commission show that at the times of the great flood disasters of 1915, 1922, and 1927, and at other times, this mountain area, although constituting only about 5 percent of the total area of this Mississippi River Basin, has contributed as much as 40 percent of the flood waters in the delta region of the Mississippi. The records show also that the Ouachita-Ozark section contributed more than 50 per cent of the peak flow on May 1, 1927, and nearly 25 percent of the peak on May 7, 1927.

The White River, a tributary of the Arkansas River that drains northern Arkansas, contributes heavily to these flows. W. W. Ashe, using data of the Chief of Engineers, United States Army, has shown that the drainage of the White River, although it contains only 2 percent of the total Mississippi Basin, contributed 7.3 percent of the flood waters of the lower Mississippi in the period 1911–27, inclusive. He pointed out that the western portion of the Arkansas River drainage, although a much larger area, contributed less than 2 percent of the same flood waters. The White River, as its name implies, originally ran clear. For the year 1927 its silt burden was estimated by Ashe at nearly 3 million tons, or 105 tons per square mile of drainage area, or 11 percent of the total silt load of the Arkansas.

Ashe estimated the total annual silt load carried by the Arkansas at some 26 million tons. Of this, he estimated only 5 million tons came from the Ouachita Province. A large part of this silt load reaches the Gulf; the heavier and coarser material, however, is deposited in slack water at or near the mouth of the Arkansas and is the chief cause of shifts of the stream banks and of the channel at that point which sometimes have serious consequences in time of flood.

The western part of the Arkansas and Red River drainages is characterized by different stream-flow conditions. Floods are much more rare, and where the Arkansas passes out of the Rockies it usually runs clear. The water problem is one of getting sufficient supplies for irrigation; in a considerable portion of southeastern Colorado and

northeastern New Mexico agriculture is dependent upon the flow of mountain streams included in these drainages.

In the central or plains portion of the two drainages floods, water supply, and erosion are all important locally. On the upper part of the Cimarron, a tributary of the Arkansas, the Folsom flood of August 1908 cost many lives and almost totally destroyed the town of Folsom. The State of New Mexico plans to construct three flood-control reservoirs on the head of the Cimarron. To impound about 50,000 acre-feet of water the Oklahoma State Commission of Drainage, Irrigation, and Reclamation has developed plans for 18 flood-control reservoirs in the Cimarron Basin which would have a storage capacity of nearly 1,750,000 acre-feet. The value of these reservoirs would depend largely upon controlling soil erosion and thus preventing sedimentation.

## TOPOGRAPHY

Topographically, the Arkansas and Red River drainages are most varied. In the extreme west the Rockies rise to elevations of 14,000 feet, some of the high peaks bearing perpetual snow. Steep slopes and rugged topography prevail in the Rockies. The foothills, below 6,000 feet, are much less broken. Largely because of the roughness of the topography, most of the Rocky Mountain forest area is classed as having a major watershed-protective influence.

The plains region, which constitutes something like 60 percent of the two drainages, is largely a gently rolling area. The "Breaks" are a badly dissected area in the Red Plains of western Oklahoma and northeastern Texas where the streams flow in cuts from 300 to 500 feet below the plains level. This area is characterized by steep escarpments or sometimes almost perpendicular cliffs with steps and terraces down to the streams.

Western Arkansas, eastern Oklahoma, southeastern Kansas, and southern Missouri are composed largely of highlands. Elevations in excess of 2,600 feet exist, although most of the hills are below 2,200 feet. The topography is much broken and slopes are steep; partly for this reason, the forests that occur on these highlands are classed principally as protection forests.

Rolling hills, seldom exceeding 500 feet in elevation, occur in southern Arkansas, eastern Texas, and northern Louisiana.

The alluvial valley at the eastern end of these drainages is practically a level floor less than 200 feet above sea level. Flood waters drain from this valley slowly. The bottomland forests are classed as having little or no watershed protective influence.

## PRECIPITATION

Great differences exist between different parts of the Arkansas and Red River drainages as to quantity, intensity, and seasonal distribution of rainfall. In the east the average annual precipitation is around 50 inches, but annual precipitation as high as 109 inches has been recorded. Toward the west the precipitation gradually becomes less, reaching a minimum of about 12 inches in the plains. It rises again to 30 or 35 inches in the Rocky Mountains, where a considerable portion of the precipitation occurs as snow.

In the lower part of the drainages about one third of the precipitation occurs during the spring months. In Arkansas 24-hour rainfall is recorded to have totaled as high as 8½ inches and exceeds 5 inches not uncommonly. In the spring flood periods of 1882, 1912, 1913, 1922, and 1927, the rainfall in the Ouachita-Ozark region ranged from 15 inches to 35 inches. In the plains region the precipitation during the winter and spring months is only about one third of the annual total. Most of the rains come in midsummer, with marked irregularity from season to season. At Twin Buttes, Colo., 8½ inches, or half the total annual precipitation, has been known to fall in 1 month.

In the foothills and lower slopes of the Rocky Mountains, cloudbursts are not uncommon. This type of rainfall has been responsible for much of the flood damage in eastern Colorado. The Pueblo flood of June 1921 which caused damage in excess of $25,000,000 and the loss of 120 lives, was caused by a rain of more than 7 inches of which half fell in 1 day.

In the Rocky Mountains proper, a great part of the total precipitation is snow. The melting of this snow causes high water in the streams but no particularly damaging floods.

### SOILS

In this region Ashe recognized four broad types of soil in addition to the alluvial soils. He described these, and estimated the proportion of the drainage areas on which they occurred, as follows:

1. Silts, very fine sands, and fine sandy loam, which are deficient in cohesion and are eroded rapidly by heavy rains. About 60 percent.
2. Clays and related highly cohesive soils, subject to erosion but not eroded so readily or destructively as the silts. About 15 percent.
3. Sands and similar light soils that have a high capacity for storing water and are only slightly subject to erosion. Nearly 10 percent.
4. Stony soils, occurring particularly in the mountain regions. Stone fragments sometimes form a heavy mantle on the surface of cleared land that greatly obstructs erosion. About 15 percent.

Forests that occur on sandy soils are in general classed as having a comparatively slight or at most a moderate influence upon watershed conditions, because these soils are highly absorptive even in the absence of a vegetative cover. Forests that grow on clay soils, as in the rolling hill lands of northern Louisiana, are for the most part classed as having a major influence because such soils are eroded so readily in the absence of cover.

### FOREST COVER

The forest area in these drainages totals about 52 million acres, forming about one third of the total area. It has three parts. The Rocky Mountain area is relatively small, a narrow strip extending about 300 miles along the eastward front of the mountains. Most of this is in the Arkansas River drainage. The eastern forest area lies largely east of the ninety-seventh meridian. The central area, relatively small in extent, lies largely in the Breaks.

In the Rocky Mountain section dense forests of pine, fir, and spruce exist. On the poorer sites the forest is open. The foothills and mesas

support only open woodlands of pine and cedar, in which grass is abundant.

In the Ozark-Ouachita section commercial forest occurs in the more humid eastern portion and the "fringe forest" in the western. About half the forest area of the Ozark-Ouachita section has now been cleared for agriculture.

The "fringe forest" is the rather scrubby forest and woodland that borders the commercial forest of the Ozark-Ouachita Mountains on the west. The Arkansas and Red River drainages contain about 10 million acres of woodland, of which Oklahoma has 7½ million acres. This woodland type, which reflects the dryness of the region, is composed largely of oak. Pine, mostly shortleaf, occurs on the better sites.

Within the plains region the woods occur as islands and stringers on the lighter soils and north slopes. Poplars and willows follow the streams far into the plains. The forest of the Breaks is largely woodland and brush, scrub oaks and brushy vegetation predominating.

Because the Arkansas and Red Rivers contribute great quantities of water and silt to the Mississippi floods, it is highly desirable in the drainages of these rivers to retard stream flow during the flood periods and to protect the soil from erosion. Watershed-protection service rendered by the forests in these drainages at critical periods is a matter of national importance.

The effectiveness of the forest cover in maintaining good watershed conditions is indicated at least in part by the behavior of the Current River, a northeasterly tributary of the White River. The upper part of the basin of this river is rough and hilly, the lower rolling. Most of it is in forest. The ordinary flow of the river is derived almost entirely from springs. Discharge measurements made by the Geological Survey show that, originating from deforested or burned areas, its ratio of maximum to minimum flow is only 65 to 1, whereas for the main Arkansas River at its mouth the ratio of maximum to minimum flow is 600 to 1.

## WATERSHED PROTECTIVE CONDITIONS BY REGIONS

### ROCKY MOUNTAIN FORESTS

In the Rocky Mountain part of the Arkansas and Red River drainages some timber has been cut but the relative inaccessibility of the forests has prevented extensive exploitation. Relatively few fires occur, though it is evident that fires have been severe in the past. In the spruce type fires have been particularly disastrous, many burns having failed to restock. Unrestricted grazing in the early days led to serious gullying of mountain meadows, which has not yet healed.

Some 80 percent, or about 2¼ million acres, of the forest area in this section is included in national forests. This acreage is protected from fire, and is so managed that cutting and grazing do not destroy the cover and that forest conditions are steadily improving.

Outside the national forests, forest land is not being given the care that its watershed values justify. Cutting has removed much of the forest cover, and recurrent fires destroy the litter. Loss of the litter has decidedly impaired watershed values, resulting in increased surface run-off, decreased absorption, and increased erosion. Overgrazing,

typical of the foothills and lower slopes, has accentuated watershed damage. The stony soils are easily erosible. Erosion caused by too heavy grazing use progresses with special rapidity during severe rainstorms. Trout Creek, near Buena Vista, Colo., furnishes an outstanding example of the results of reduction of cover. Formerly this stream for 20 miles was clear and willow lined, and gave no evidence of erosion. Timber cutting in recent years has been followed by fire and overgrazing. The fertile bottomland soil has now been washed away, all the willows are gone, and the stream is imbedded in a deep, wide gully practically throughout its length. Heavy rains now cause floods which result in damage to agricultural lands and to transportation improvements.

### OZARK-OUACHITA FORESTS

Lumbering on a large scale in the eastern mountains began about 1890. It was concentrated on the pine lands at first, but soon moved into the hardwoods. The first cuttings were usually light, but as time passed heavier cutting became the rule.

Slashings rarely escaped burning. Repeated fires gradually deteriorated the forest. In many places, especially on the poorer soils, the stands became more or less open or brushy. A recent study of hardwood stands on the Ozark National Forest by the Central States Forest Experiment Station showed that only 1.5 percent of the stands studied were of seedling origin.

Settlement in the Ozark-Ouachita region began about 1830. By 1860 the greater portion of the White River Valley of northern Arkansas and most of the Arkansas Valley to the Oklahoma line had been settled. The prairies and oak openings were first to be occupied. A great part of the alluvial and rolling hill land of the main Arkansas Valley has since been put into cultivation.

Clearing and cultivation of row crops on hillsides has led to rather general erosion as the humus in the top soil was exhausted or washed away, and to subsequent abandonment of crop lands. Many of the hill farms should never have been cleared. Census data show that the crop-land area in Garland and Baxter Counties of central Arkansas has declined by nearly one third, and that a similar decline has taken place in counties in the forest belt of southern Missouri and northern Louisiana. Serious erosion is occurring in the hill lands in northeastern Texas. Certain of the soil types, such as the loess found on Crowley's Ridge in northeastern Arkansas, are eroded rapidly into deep gullies that not only make further cultivation impossible but in many instances prevent reforestation. Fortunately the shortleaf pine of the mountains and the loblolly of the lower slopes and bottoms bear seed frequently and scatter their seeds widely, and thus quickly reclaim abandoned fields. In many cases, however, fires on the restocking fields prevent maintenance of the good forest and litter cover so necessary to proper watershed conditions.

In Arkansas, which lies almost entirely in the Arkansas and Red River drainages, the average area burned over annually in the 5-year period 1926–1930 was some 2,350,000 acres of a total forest area of 22 million acres, this burned area including 2,190,000 acres of the unprotected forest area of 18½ million acres. Cutting and fire together have deteriorated the forest on approximately half the total forest area of Arkansas. On some of these lands there is a brush or other

low type of cover, but frequent fires prevent the development of a good litter cover.

For the Ozark-Ouachita section as a whole, grazing is not a factor of great importance in watershed conditions. Some hardwood forests are grazed, with consequent opening of the stand and dissipation of the litter. Cattle are turned loose on pine lands, also, especially in the Kisatchie Hills section of northern Louisiana, but not in sufficient numbers to create critical conditions through depleting the minor vegetation. The practice of burning for the purpose of range betterment is the most serious factor connected with grazing.

### FRINGE FOREST

In Missouri, Oklahoma, Kansas, and northern Texas, extensive areas of woodland have been cleared for agriculture. As settlement increased the practice of burning the woods became prevalent. Under burning, humus conditions deteriorated and the perennial herbs gave way to annual grasses. Overgrazing, also, has greatly depleted the vegetative cover and in the stands thus opened litter cover cannot form because winds scatter the leaves.

The extent of fires in the fringe forest type is indicated by fire records for Oklahoma, where the fringe forest makes up about two thirds of the total forest area. The records do not separate the woodland type from the commercial forest, but probably at least half and possibly two thirds of the fires recorded occurred in the woodland type. In 1931, 7,600 forest fires in Oklahoma burned almost 2½ million acres of the 12½ million acres of forest land in the State and did damage to the extent of more than $3,000,000. This damage estimate takes no cognizance of watershed values impaired or destroyed.

The effect of fire in this type is shown by investigations recently made at the Red Plains Erosion Experiment Station, near Guthrie, Okla., which are described in detail in the discussion, "Consequences of Disturbing the Forest Cover." These investigations showed that the run-off from a burned plot of post-oak timber was more than 110 times as great as the run-off from a similar unburned plot. Erosion similarly removed 15 times as much soil from the burned area. Although the litter found in post oak woodland is not so dense or so effective in limiting run-off as that in forests of many other species, in this experiment it showed great value for flood control.

Erosion is common on the upland cultivated soils, especially on those that are hilly or rolling and not terraced. As a result of this erosion heavy silt loads are carried by the streams of southwestern Missouri and eastern Kansas. Of the two Hanceville soil types the State forester of Oklahoma said: "Much of the land when cleared is so subject to erosion that only a comparatively few crops can be raised before it has to be abandoned." In the Wichita and Arbuckle Mountains of central Oklahoma, agriculture on steep hill lands has caused both sheet and gully erosion. Many of the eroded lands have been abandoned. On these lands a forest cover is slow to return.

In 1930 an erosion survey by the Oklahoma Agricultural College disclosed that of the approximately 16 million acres of cultivated land in the State 13 million acres was subject to excessive washing, 6 million acres had reached the gullying stage, and 374,000 acres was

so badly gullied that farm machinery could not be used on it. The survey revealed also that in the preceding 3 or 4 years 1,359,000 acres of formerly tilled land had been abandoned because of erosion.

#### BREAKS FORESTS

In the Breaks sparsely wooded, brush-covered, or even naked slopes occur in the gorges of the Arkansas and Red Rivers and their tributaries. In many places the vegetation is in such delicate balance that any disturbance results in extensive gullying. Erosion has been intensified by the torrential character of the rains, and has been accelerated by overgrazing.

Erosion from the Breaks probably accounts for two thirds of the silt load of both rivers.

### WATERSHED-PROTECTIVE CONDITIONS BY TYPE OF LAND OWNERSHIP

#### NATIONAL FORESTS

The value of the forests in the Arkansas and Red River drainages has been recognized by the Government through the establishment of national forests, which include much of the headwaters forest area in the Rocky Mountains, and through plans for national-forest extension. On these national forests, conditions resulting from overgrazing are being corrected through range management, methods of cutting timber that provide for restocking are in effect, and fire control is on an organized basis. Watershed conditions are therefore improving. In the Ouachita-Ozark highlands, the national-forest area amounts to some 1,250,000 acres. Here, likewise, measures have been put into effect to restore the forest cover where it has been depleted and to protect the forests from fire, and timber cutting is regulated.

#### PUBLIC DOMAIN

Some 770,000 acres of unreserved public-domain forest land still exists in these drainages, mostly woodland areas at the headwaters of the rivers. Conditions are less satisfactory on these lands than on the national forests, because management is lacking. The Forest Service recommended to the Public Domain Commission in 1930 that many of these lands be added to existing national forests.

#### STATE LANDS

State ownership of forest land in the Arkansas and Red River drainages covers only 105,000 acres. Most of the State forest lands are so located and in such small units that adequate management is practically out of the question. They are consequently in about the same condition as private lands.

#### PRIVATE LANDS

Private owners of forest lands, for the most part, have not concerned themselves with maintaining good watershed conditions on their holdings. A number of owners are endeavoring to protect their lands from fire, but this effort is not general; in 1931, fire protection was afforded for only 17 percent of the privately owned forest area of

Oklahoma and Arkansas. Some companies owning extensive tracts of timberland in Arkansas and Louisiana have purchased the lands of settlers believed to be responsible for frequent fires.

Some landholders are cutting their timber in such a way as not to cause deterioration of the stand and on a continuous-production basis.

Much idle farm land is potential forest land, since it is at least exceedingly doubtful that it will again be needed for crop production for many years.

### MEASURES NEEDED FOR WATERSHED PROTECTION

In the Arkansas and Red River drainages the adoption of adequate fire-control standards such as are outlined in the section of this report entitled "Protection Against Fire" would better watershed conditions more quickly than any other measure. Adoption of simple forestry practices would contribute greatly to the improvement of watershed conditions. These would include better cutting practices and the elimination of grazing from cut-over hardwood areas—at least until the forest cover has reestablished itself. Clearing of hills that are too steep for profitable cultivation should not be permitted. The present widespread erosion of hill crop lands and the increasing abandonment of these lands indicate that cultivation of slopes the grade of which exceeds 12 or 15 percent is uneconomic except under most unusual circumstances.

Forest planting is needed to supplement natural restocking, on abandoned agricultural lands and on some forest lands. Some 500,000 acres in the Ozark-Ouachita highlands and about 250,000 acres in the upper coastal plain region should be reforested.

Special measures of erosion control and probably of water control are needed on many areas. These would include such devices as soil-saving dams on badly gullied abandoned agricultural lands, check dams on mountain areas to assist in holding back the surface flow, terracing of some of the most severely eroded abandoned agricultural lands, sodding of some particularly bad areas, and stream-bank correction to prevent undercutting.

In the Breaks areas, grazing, which is probably more responsible than any other factor for extensive erosion, should be more closely regulated. Much can be done to control severe washing and gullying by such devices as check dams, erosion fences, etc. Such devices can only be of lasting benefit if cover conditions are properly maintained. Investigation should be made into the possibility of reducing by range management, tree planting, reseeding of depleted range land, and special erosion-control measures the quantity of silt added by this area to the burden of the Arkansas and Red Rivers.

In these drainages satisfactory cover conditions might be expected to result from extending to the unreserved public domain and to private forest lands the practices now in effect on the national forests. It is doubtful that the private owner can undertake to put these measures into effect. Forest planting, elimination of grazing, and other needed erosion-control measures would result in heavy charges against the land. For this reason, and in view of the relationship between forest conditions in these drainages and the floods of the lower Mississippi, public ownership of about 19.2 million acres in

the drainages appears desirable. This will include about 2.2 million acres of abandoned agricultural lands and 17 million acres of forest land. The very large national interest created by conditions in these drainages suggest that this public ownership be Federal rather than State or other local.

## LOWER MISSISSIPPI RIVER BASIN

Floods in the Mississippi Valley are most common and of greatest concern in the "Delta" or bottomland region of the lower Mississippi Basin. Here all the major tributaries of the big river pour in their flood contributions, the control of which constitutes the outstanding flood problem in the United States. Responsibility for the havoc wrought by floods in the bottomlands of the lower Mississippi Basin must be attributed largely to flood waters from other sections. However, were the latter all under control, there would still be a local flood problem of considerable magnitude in the lower Mississippi Basin as a result of the condition of its watershed and the relatively large area of alluvial bottomlands on which its own flood waters are poured.

### LOCATION AND DESCRIPTION OF DRAINAGE BASIN

For purposes of this discussion, the lower Mississippi Basin (shown in fig. 6) includes not only the alluvial lands extending from Cairo, Ill., to the Gulf of Mexico but also the upland watersheds of the streams draining directly into the lower river. These are small and relatively unimportant streams with the exception of the Yazoo River which heads in the uplands of north-central Mississippi and flows over a wide alluvial flood plain to join the Mississippi River at Vicksburg.

The lower Mississippi Basin is from 500 to 600 miles long and up to 150 miles wide. It has a total area of 33,886,000 acres. Nearly one half the total area is in overflow bottomlands. Here forest occupies lands not protected by levees and lands behind the levees which have not been cleared for agriculture. These overflow areas are often covered with water during the winter season and thus perform an important service in flood control since they serve as natural storage reservoirs for the detention of flood waters.

The remainder of the drainage basin consists of rolling to hilly uplands. The principal area—the Mississippi bluffs and silt loam uplands—borders the Mississippi Delta on the east and extends in a strip 35 to 100 miles wide throughout the length of the drainage basin. A much smaller but similar upland area known as Crowley's Ridge is located west of the Mississippi River. The latter area occupies a narrow belt up to 10 miles wide and about 200 miles long and rises about 150 feet above the level of the surrounding bottomlands. Also included in the drainage is a relatively small area of hilly country in southeastern Missouri.

These uplands because of their location with reference to low-lying bottomlands and because of their present condition play an important part in the destructive floods and soil erosion that are the major watershed problems of the drainage.

## STREAM FLOW AND FLOOD PROBLEMS OF THE DRAINAGE

As has been pointed out, major overflows in the Mississippi Delta have their source outside the boundaries of the drainage basin. In the lower Mississippi Basin the outstanding flood problem directly attributable to run-off from within the drainage occurs in the Yazoo Delta. This is an alluvial flood plain 180 miles long and up to 65 miles wide, lying between the Yazoo and Mississippi Rivers north of their confluence in western Mississippi. Here major floods occur periodically every few years, frequently during the winter months after heavy and prolonged rains. They originate in north central Mississippi on the watersheds of upland tributaries, and are the result of surface run-off from the uplands poured quickly and in large volumes on a region of nearly level topography and poor drainage. These overflows often cover hundreds of thousands of acres and do widespread damage. The most recent Yazoo flood occurred during the period December to February, 1931–32. This overflow, the greatest on record, inundated some 600,000 acres and imposed great hardships. According to estimates of the United States Weather Bureau, it resulted in property damage of almost $1,500,000, not including the damage to crops and livestock.

Floods of less magnitude occur on the bottomlands of other streams draining the uplands of the lower Mississippi Basin. These streams have a low gradient and are rather sluggish. Some have developed flood plains several miles in width and these are flooded almost annually during periods of heavy rainfall. On these bottomlands, the most disastrous floods occur during the summer months when heavy rains produce overflows that inundate growing crops.

Although the normal discharge of these streams is slow, discharges at flood are turbulent. Even at normal flow the water is strongly discolored and carries large volumes of silt. In addition, flood waters transport enormous quantities of heavier materials and, during periods of overflow, often cover productive alluvial farm lands with an infertile blanket of sand and gravel. The channels of creeks and other small tributaries are frequently filled with such detritus, thereby causing more frequent and extensive overflows on adjacent bottomlands. The sediment carried by the headwater drainages becomes of greater economic concern when it reaches navigable streams and is deposited in the channels, thus necessitating costly dredging operations. In 1931, such work in the Memphis district of the Mississippi River cost nearly $800,000. For the lower river as a whole it has cost to date some $19,000,000 to remove soil eroded from the watersheds of the Mississippi River system.

The streams of the lower Mississippi Basin are perennial and flow throughout the year. The flow, however, is not uniform and is particularly erratic for those streams draining only upland watersheds. Irregularities in flow are indicated by stream gage records of the United States Geological Survey which show, for the Coldwater River, a ratio of maximum to minimum discharge of 725:1; for the Yallobusha River, 486:1; and for the Yazoo River 43:1. The erratic behavior of these streams in common with others in the basin is evidenced during periods of heavy and prolonged rainfall when rises

are comparatively rapid. Flood stages are often reached in a few days and subsidence occurs just as quickly when the bulk of the surface water has drained away.

### CHARACTER AND CAUSES OF EROSION

While erosion problems are confined to the upland portions of the drainage basin they are intimately related to the flood and stream-flow problems of the lowlands since both are quite largely the product of uncontrolled surface run-off. That the uplands of the basin are especially susceptible to erosion is shown by the results of surveys made in 1930 by the Southern Forest Experiment Station. These reveal that 28 percent of the entire upland area in northern Mississippi is denuded land, barren of cover and actively eroding. In 4 counties more than 30 percent of the total area is eroding, while in 2 more than 40 percent is so classed. An additional area of 27 percent of the region is abandoned land, the abandonment of which in part was caused by soil impoverishment. These data apply specifically to the upland watersheds of the streams tributary to the Yazoo River, but the widespread and destructive soil destruction found in this portion of the Mississippi silt loam uplands characterizes a large part of the entire region.

A mere quantitative estimate of erosion, however, gives little indication of the real seriousness of the problem. Much of the erosion is of a peculiarly destructive type. Washes 20 to 30 feet in depth are common and occasionally gullies nearly 100 feet in depth are found. Such erosion has made these silt uplands and their counterpart in the upper Mississippi drainage, a region of outstanding watershed and erosion problems.

A combination of factors is responsible for the serious erosion and flood problems of the region. The precipitation is heavy and averages, for the region, between 40 and 55 inches, more than half of it falling when the cultivated lands are bare of cover. Most of it comes as numerous rains, frequently torrential in character. According to United States Weather Bureau records, there have been about 35 days annually over a 20-year period with rainfall of one fourth inch to 1 inch and about 4 days with rains of 2 inches and over. A maximum precipitation of 4 inches an hour and 9 inches in 24 hours is reported.

The soils of the region are highly erosible and consist mainly of silt loams and clay loams derived from loess. When protected by forest or other vegetative cover these soils do not erode easily and are capable of absorbing large quantities of rainfall. When bared, however, they wash badly. The silty soils are frequently underlain at depth of a few feet by unconsolidated sands and other incoherent materials. Once a gully has cut through the surface loams and exposed these unstable strata, erosion proceeds on a gigantic scale, and is extremely difficult to control.

The unwise use of these uplands for agriculture is responsible for practically all of the soil wastage that has occurred. The cultivation of cotton and corn to the exclusion of other crops leaves the soils exposed to the action of the elements during much of the year. Even on moderate slopes the soil losses from the cultivated fields of the region are enormous. Forest Service studies at Holly Springs, Miss.,

show that a single rain falling on a cornfield having a 10 percent slope washed soil from a study plot at the rate of 23 tons per acre. Preliminary results also show that under such conditions only 2 to 3 years are required to wash away 1 inch of topsoil These data, substantiated by observations, indicate that the cultivable life of these upland soils ranges from 5 to 20 years.

As a result of such conditions, wholesale abandonment of farm lands has occurred. The surveys of the Southern Forest Experiment Station indicate that on the upland watershed of the Yazoo River, totaling roughly 3,487,000 acres, there are 813,000 acres of abandoned farm lands and almost as large an area additional of land formerly abandoned but now used for pasture. More intensive surveys of five farms also show that more than 50 percent of the total area of each farm had been abandoned because of erosion. The abandonment of eroded marginal lands is an important factor in the growth and spread of gullies which usually proceed unchecked once the fields are taken out of cultivation. Unless control measures are promptly taken, complete destruction of the abandoned field results.

## RELATION OF FORESTS TO FLOOD AND EROSION PROBLEMS OF THE DRAINAGE BASIN

The original forest of the uplands was largely mixed pines and hardwoods. In the southern portion of the region loblolly pine is predominant and seeds in abundantly on waste and abandoned areas. In northern Mississippi shortleaf pine occurs in mixtures with the mixed oak forest. Further north, the forest consists almost entirely of oak, hickory, and other hardwoods.

Clearing, primarily for agriculture, has been extensive. Less than 25 percent of the uplands area originally completely timbered is still in forest.

Lumbering is now of minor consequence in this region. In the past, cutting as a rule was not heavy, and stands were culled of their large white oak, yellow poplar, and other desirable species, rather than cut clear. Later cuttings for ties and other minor products have seriously depleted the stands. Logging seldom produced devastation consequently, unless the logged-over area were put into cultivation, protection values were little changed. Within the range of the pines, cutover areas reseed within a few years as a rule and reproduction becomes established in spite of fire and other mistreatment. Hardwood stands are rarely cut clear and reproduction is usually complete.

Fire is a much more serious factor than cutting, because fires, often purposely set, burn over extensive areas of forest annually. Litter accumulations, so necessary to good watershed conditions are thus prevented, and in those areas where repeated fires occur at short intervals, the forest often has greatly deteriorated.

Grazing is typically a woodlot problem, although in some localities the stock is turned loose in the woods. Most of the really serious damage to the forest is done in cut-over hardwood stands where repeated browsing of the new growth tends towards the formation of brushy stands or in some places rather open woods.

It is estimated that in the entire lower Mississippi Basin there are approximately 17,854,000 acres of forest land, of which roughly 6,857,000 acres have a major influence on watershed values and 1,877,000 acres have a moderate influence. The relative influence ascribed

to each class of forest is based largely on the location of the forest with respect to regions where conditions are particularly conducive to excessive surface run-off and erosion. The forests of each protection class are shown in figure 6.

The forests having a moderate and heavy influence are in the silt loam uplands, Crowley's Ridge, and the hill lands of southeastern Missouri. However, only 25 percent or less of the total area of these erosive uplands is now forested. Therefore, if the protective influence of forest is to be more fully realized there should be marked extension of the present forest area and the restoration of forest cover to large areas of now idle land. Such upland forests as remain afford somewhat less than the maximum possible protection, but they unquestionably exert a considerable and beneficial influence on erosion and on stream flow. In the Yazoo River flood period of 1931–32, the Southern Forest Experiment Station found that of the 27 inches of rain that fell, 62 percent ran off cultivated fields immediately and carried soil with it at the rate of 34 tons per acre. In barren abandoned fields the run-off was 54 percent of the total rainfall. During the heaviest rains from 75 to 95 percent of the rain falling on these classes of land became surface run-off. On the other hand, of the 27 inches of rain falling on an undisturbed oak forest, less than 0.5 percent ran off the surface, taking only about 75 pounds of soil per acre. The run-off from a plot located in a scrub-oak forest, and with a litter cover, was 2 percent of the rainfall.

For the period of observation, the surface or flood run-off from land in cultivation was 127 times greater than from forest land, and the eroded soil over 900 times greater.

## WATERSHED AREA IN NEED OF SPECIAL ATTENTION

As the upland area of the lower Mississippi Basin has such an intimate bearing upon floods and upon the amount of eroded material which reaches the Mississippi River, it is one of the outstanding critical areas of the country, one in which every effort should be made to bring about more favorable conditions.

Of these uplands, the situation in the Yazoo River drainage probably is in most need of early attention. From this unit of roughly 3,487,000 acres gross, surface run-off is quickly concentrated in drainage channels and the flood waters are almost immediately debouched into the low-lying, poorly drained Delta where extensive areas of true agricultural land are subject to destructive inundation as the result of unwise land use in the adjacent uplands. Residents of the Yazoo Delta, one of the most productive of all agricultural regions, with half of its nearly 6 million acres in fertile farm lands, have made numerous demands for the construction of a complete system of levees, which would protect them not only from the Mississippi floods but also from those of the Yazoo as well. Engineers estimate, however, that adequate levee protection from floods would cost many millions of dollars. In this whole situation lies strong evidence of a need rather to control run-off at its source through changes in land utilization in adjacent uplands.

Something like 35 percent, or 1,214,000 acres, of the Yazoo uplands are in cultivated crops. This large area appears to be a serious obstacle to any program aimed at complete control through forest cover.

Of the cultivated area, the data indicate that about 470,000 acres, or 13 percent of the total, is badly sheet eroded and hence will quite likely be worn out and abandoned within the next 10 or 15 years. These eroded submarginal lands could very easily be converted into forest or pasture if remedial steps were taken promptly at time of abandonment. Unless a vegetative cover is quickly established, uncontrolled run-off soon transforms these old fields into gullied wastes which are difficult to reclaim. An additional 350,000 acres of eroded pasture land will quickly revert to forest or other native vegetation if protected from livestock.

Of the total area of the Yazoo upland watershed, 23 percent, or about 813,000 acres of once arable land, has been abandoned and is now lying idle. Of this area about 500,000 acres is not seriously eroded and is reverting naturally to forest and grasses. The remaining 313,000 acres is, however, very badly gullied and actively eroding. The preliminary run-off studies in northern Mississippi indicate that the areas which are or have been in cultivation are the outstanding contributors of flashy run-off and suffer most of the soil losses. As the badly eroded and impoverished abandoned lands will not revegetate except after a long period, it will be necessary to establish the forest cover largely through artificial means. About 250,000 acres probably need planting, many of which need special erosion-control measures as well.

The planting of these severely gullied lands offers many difficulties that are at present being investigated. In certain cases, however, such plantings have already proved successful and practicable. In western Tennessee, black locust plantations have been established on many eroded fields. These plantations in 10 to 15 years have not only effectively stopped erosion but have developed such a cover that soil and water conditions approach those of a much older forest.

Plantations alone cannot stop the further extension of gullies. They are too deep and the erosive processes are taking place too rapidly. Special works, such as soil-saving dams and check dams, are needed. Seeding and sodding of slopes will be required. Probably 150,000 acres in all will require special treatment. The upland types receive little fire protection. Adequate fire control would permit many abandoned lands to restock fairly promptly and would enable the restocking lands to develop a denser cover. It would also permit the formation of a good litter layer.

Erosion on the areas in need of planting has already progressed far beyond the stage where the land can be again reclaimed for cultivation. Furthermore, from 65 to 85 percent of the farm lands, according to 1930 census figures, are in the hands of tenant farmers who have little incentive for improving them inasmuch as the absentee owners are, as a rule, indifferent to their destruction. At the present rate of abandonment, it seems highly probable that in 10 or 15 years less than 25 percent of the uplands area will be in cultivation, provided that new areas are not cleared nor old fields again put into cultivation.

At the present time practically all of the silt loam uplands are in private hands. In view of local conditions and the abandonment of agricultural lands, it appears unlikely that watershed conditions can be corrected through the efforts of the private owners. These efforts would place a heavy financial burden on the owner and most of them do not hold out to him the possibility of monetary return. Public

acquisition of a large area therefore seems certain, and, in view of the national interest involved, Federal participation may be called for.

Study of the watershed needs in the lower Mississippi River Basin leads to the belief that some 5.8 million acres should be in public ownership. Of these 1.2 million acres are classed as abandoned and eroded agricultural lands and 4.6 million acres as forest lands. All of this land is in the region having a major influence on streams. Public ownership and management of these lands will assist greatly in restoring more favorable conditions of water flow.

## CALIFORNIA DRAINAGES

An honorary watershed committee appointed by the Governor of California, in a report published in 1932 under the title, "Forestry in the State-Wide Water Plan", states: " * * * the best possible development and conservation of the waters of the State are of the utmost importance to the continued prosperity of both the rural and urban communities of California." In this committee's opinion "any great increase in population in this State is impossible without the fullest feasible conservation of its waters. Without a sound program of water conservation * * * California cannot continue to maintain even its present population."

The California drainages (fig. 11) as here considered include all lands in the State except the eastward slope of the Sierra Nevada, which drains into the Great Basin, and include also portions of Oregon that are drained by the Klamath and Sacramento Rivers. According to the 1930 census these California drainages include 4,765,000 acres of irrigated land, and the value of this land, together with that of improvements and equipment and of irrigation enterprises serving the land, totals nearly $3,000,000,000. This high value is due to conditions favorable to production of high-value fruit and other crops on a considerable part of the irrigated land. The very large urban population of the drainages makes a heavy demand for water for municipal use. In waterpower development California ranks first among the States, with a present installed capacity of 2,321,374 horsepower which has been yielding an average output of about 1,173,000 horsepower. It is expected that ultimate development will raise the average output to 6,674,000 horsepower available 50 percent of the time.

In order most effectively to develop and conserve its water resources California has developed a State water plan that calls for expenditure of approximately $500,000,000 in constructing reservoirs and canals. The proposed reservoirs would be located largely in the foothills of the Sierra Nevada with a view to impounding flood waters from the higher watersheds, and the canals would transport water from areas of surplus to areas of inadequate supply. The water shortages which this plan is designed to overcome in part occur principally in the San Joaquin River Basin.

The State watershed committee estimates that the mountain and foothill areas upon which the valleys and lowlands depend as their source of water aggregate some 40 million acres, approximately 40 percent of the total land area of the State. Effective precipitation occurs on these areas during a period of about 5 months in the winter and early spring. Summer rains are not uncommon in the northwest coast belt and in the Sierras but are extremely rare in the other parts

of the State. Furthermore, summers are hot. Precipitation occurs below the 2,500-foot contour as rain, between the 2,500-and 5,000-foot contours as rain and snow, above 5,000 feet as snow. Annual precip-


FIGURE 11.—California drainages.

itation totals 50 inches or more in the northern Sierra Nevada and in the northern coast ranges. It gradually decreases toward the south. Likewise the proportion of the precipitation that accumulates as snow in the mountains decreases toward the south. In view of the long, dry summers and the present incomplete development of reservoir storage the heavy winter snow pack, especially in the Sierras, is

of the utmost importance to both power and irrigation interests. Run-off from snow melt at the higher elevations remains plentiful well into July, and a rather well-sustained flow continues through the summer in many of the streams from drainage of water that has seeped into the soil. Upward of 2,500 mountain meadows and 1,500 lakes act as natural storage basins helping to maintain this stream flow.

The mountain areas are largely forested, chiefly with conifers. Interspersed with the coniferous forests are extensive brush fields, many of which, under proper management, could be converted again into coniferous forest. The foothills are covered mainly with brush and chaparral, with lesser areas of woodland and grassland. As a whole the forests of the California drainages amount to approximately 29,780,000 acres, this total including timberland, woodland, chaparral, and brushland.

While the bulk of the forest lands are still virgin, extensive areas show the effects of destructive fires to which they have been subjected in the past and of destructive lumbering. The foothills, in particular, have suffered disastrously from fire. Overgrazing, also, has seriously injured the watershed cover of forested lands.

Destruction of watershed cover has resulted in abnormal erosion over millions of acres, particularly in the foothill belt. The eroded material is rapidly silting up reservoirs, canals, ditches, and other engineering works, shortening their life or adding to the cost of maintenance far beyond what silting from normal erosion would do. Eroded material also seals the surface soil of gravel beds at the mouths of canyons over which run-off water is spread in order to increase storage in subterranean basins. This method of increasing water storage is used extensively in southern California. The silting up of these gravel beds retards the salvage of flood waters. The heavy draft on underground water supplies is lowering the water level and increasing the cost and difficulty of irrigating from wells.

The eroded material, added to the rapid run-off from exposed slopes, greatly intensifies the destructiveness of floods. In 1928 North Sacramento and other towns of the Sacramento Valley suffered a loss of $736,000 as a result of floods in the Mokelumne, Consumnes, American, and Feather-Yuba Rivers.[67] Destructive floods have occurred in many parts of the State.

## FOREST COVER IN RELATION TO WATERSHED PROBLEMS IN INDIVIDUAL DRAINAGES

On the basis of watershed problems and the relation of forest cover to them, the California drainages logically divide into six units: (1) The San Joaquin River Basin; (2) the Sacramento River Basin; (3) the north coast drainages, including that of the Klamath River; (4) the central coast drainages; (5) the desert basin; and (6) the south coast drainages. These units differ as to physical and other factors contributing to the influence of forests upon water supply, erosion, and floods, as to the demand for water, and as to other watershed considerations.

California watershed lands are chiefly of three classes—forest, range, and agricultural. It is probable that erosion and the influence

[67] Taylor, N. R. "The Floods of March 1928, in the Sacramento Valley," pp. 100–102. Monthly Weather Review, March 1928.

of run-off on floods is more serious on range and sloping agricultural lands than on forest lands. This discussion covers forest land, range and agricultural lands occurring within the forest in such a way that the watershed relationships cannot be effectively separated, and lands cleared of timber that should have remained forested. The following discussion of forest conditions and use will deal both with the timber and its use by cutting and with the forest-range plants and their use by grazing. Destructive factors such as overcutting or improper logging, fire, and overgrazing are considered, as they influence both the timber and the understory of other vegetation.

### SAN JOAQUIN RIVER BASIN

Water is in especial demand in the San Joaquin River Basin, which includes together with the broad San Joaquin Valley many westward drainages from the southern half of the Sierra Nevada and a narrow strip of the eastern part of the Coast Range. Approximately 2,405,380 acres are now irrigated and a total of 3,773,964 acres is irrigable. The Hetch Hetchy project, costing $126,500,000, is designed to provide San Francisco and its environs (1930 population, 634,394) with an adequate water supply drawn from the Tuolumne drainage of the Sierra Nevada. Many valley towns and cities, also, depend upon the forested watersheds of this basin for their water supplies. Numerous power plants have been developed or are contemplated. On the whole, the water supply is inadequate.

Toward the southern part of the basin the water shortage is intense. The State water plan proposes to augment supplies in that part from those farther north, through the construction of reservoirs in the Sierra Nevada foothills and of canals to transport the water.

Approximately 22 percent of the basin's area is occupied by coniferous forest, which occurs in a belt along the west slope of the Sierra Nevada. It is from this belt that most of the water comes. The 40 to 50 inches or more of precipitation in the northern part and the 20 to 30 inches in the southern part occur chiefly as snow, which accumulates, particularly in the northern part, in such a way as to furnish large reserves for summer flow. In the main, timber stands are dense and there is a good litter cover which, together with undergrowth, completely covers the soil. Accordingly, snow melt is retarded and there is good absorption into the soil. Normal erosion of the soil, which is derived largely from granitic rocks, does not exceed soil formation unless the cover of vegetation is removed. All this area has been classed as of major watershed influence. In the heavily forested belt, which is chiefly included in national forests or national parks, watershed conditions are generally good. National-park management aims to keep the forest in as natural a condition as possible, and national-forest lands are administered to maintain watersheds in the most satisfactory condition feasible.

In the foothills where the woodland and brush types occur, an exploratory survey by the Forest Service indicated that abnormal erosion is very serious even though rainfall totals only 15 to 25 inches. Much of the woodland and brush area has passed into private ownership, although parts of it remain as unappropriated public domain. Fire is the greatest threat to the woodland cover. A great part of the foothill belt is burned yearly. Many fires are set by stockmen in

the belief that fire will keep the brush cover open and improve grazing or by owners for the purpose of clearing land. The effect of destroying cover by fire has been excessive loss of soil from heavy rains. As was stated earlier in this section, this loss amounted to 4 cubic yards of soil per acre on experimental plots near Northfork during one winter rainy period, during which only the barest trace of detrital material was washed from adjacent unburned woodland plots.

Woodland areas in the foothills furnish winter grazing for herds that occupy higher range during the summer months. Long, dry summers normally make it difficult for forage to grow, and the recent series of dry years has so depleted the forage cover on these vital watersheds that the problem of range feed supply and erosion control has become alarming. Studies recently begun in the foothills by the Forest Service are indicating why overgrazing has often been destructive to forage and watershed values there. Annual plants begin growth immediately following the start of winter rains, and livestock are usually placed on the range at that time. Growth in early winter is extremely slow; and the scant vegetation, depleted by overgrazing, does not effectively protect the soil against erosion from heavy rains. In addition, accelerated erosion has resulted from the clearing for agricultural development of certain sloping lands that should have remained in woodland. Because of the great danger of erosion when the vegetation is depleted, and the seriousness of the erosion damage to irrigation enterprises as well as of loss of soil productivity on the eroded lands, woodland and brush areas in the foothills have been classified as of major watershed-protective influence.

### SACRAMENTO RIVER BASIN

The broad, rich, irrigated Sacramento Valley is bordered by mountains rising in a semicircular belt. Precipitation in the mountains is heavy, in general, occurring largely in winter as snow which at the higher elevations accumulates to considerable depths. Over most of the westward slopes of the Sierra Nevada, annual precipitation varies from 40 to 75 inches. On the plateau area in the northeastern part of the State drained by the Pitt River it varies from 15 to 35 inches. Along the east slope of the Coast Range it varies from about 20 to 35 inches. The melting of heavy snows furnishes abundant run-off for irrigation and power, especially in the spring and early summer. Rapid melting of the snow pack or heavy rains may cause damaging floods; for example, as has previously been mentioned, the March 1928 floods in the Sacramento Valley caused a loss of $736,000.

About 40 percent of the Sacramento River Basin is occupied by a dense forest of conifers. This coniferous forest develops a thick ground litter of needles and twigs. A rather dense stand of undergrowth, largely brush, also occurs. Where the vegetative cover has not been devastated by fire, destructive logging, or excessive grazing, it is effective in regulating run-off, and especially in preventing erosion, and is classed as of major watershed influence. On areas covered with partly decomposed lava and largely level, especially on the plateau in the northeastern part of the State, moisture readily penetrates the soil and the danger of serious erosion is slight. On such areas the forest, which is largely ponderosa pine, is considered to influence watershed values but slightly. Much of the Coast

Range area is covered with soils derived from sedimentary rocks such as sandstones and shales, which absorb water slowly and when exposed are readily eroded. Soils in the Sierra Nevada derived from lavas and basalts also are easily eroded when well decomposed. On soils of these classes the forest exerts a major watershed-protective influence by facilitating penetration of water from the heavy snow blanket and by controlling erosion.

In the Sacramento River Basin as in the San Joaquin Basin, the woodland and brush areas have been classed as having a major watershed-protective influence. The woodland and brush types occupy nearly 25 percent of the area of the basin. Where dense, the brush type forms a heavy mulch of litter on the soil, which retards run-off and erosion principally by maintaining the soil profile at its maximum absorptive capacity, its own absorption of water being a minor factor. Unfortunately from the standpoint of watershed protection, the owners of most private lands use fire to clear them or open the brush. On sloping lands, destruction of the cover is nearly always followed by severe erosion.

Erosion control is particularly necessary in this basin because of the importance of the reservoirs planned for the foothill belt under the State water plan. There is grave danger that the largest of these, the Kennett Reservoir in the upper Sacramento Basin, would fill with silt very rapidly. On an area near Kennett, where smelter fumes have caused complete destruction of all vegetation on upwards of 67,000 acres and partial destruction on 86,000 acres, "the hills are everywhere cut and gashed by the long furrows which run from practically the top of the hills to the bottom in straight lines, growing deeper and wider as they near the watercourses, which formerly were forest-lined, and now are gravel washes in the summer and torrents during the winter".[68]

### NORTH COAST DRAINAGES

The north coast drainages extend northward along the Coast Range from San Francisco Bay and include the Klamath River, which drains a small part of southwestern Oregon east of the Cascades. Coniferous forest occupies more than 55 percent of the area of these drainages. Woodland occupies more than 15 percent of the area. Although precipitation in the upper reaches of the Klamath River watershed is about 20 inches or less, at some places along the Coast Range precipitation reaches 80 to 100 inches, the highest in the State. Most of this precipitation comes in winter, and at the higher elevations snow accumulates to considerable depths. Since precipitation is heavy, the forest cover good, and the demand for water relatively light, there is a considerable surplus of water over much of the drainage area, although in parts, such as the upper Klamath River, storage is necessary to assure a sustained supply. In this upper Klamath River area open volcanic soils absorb water so readily that the forest exerts only a slight influence on watershed values.

In the Coast Range serious erosion is possible, because of the heavy precipitation, steep slopes, and soils that are eroded readily when

---

[68] Munns, E. N. Erosion and Flood Problems in California. Calif. State Board of Forestry Rpt. to the 1921 Legislature on S.Con.Res. 27. 1923.

exposed. Very severe sheet and gully erosion is occurring, for example, on slopes cleared for cultivation. Most of the higher Coast Range forest areas have been considered as having a major watershed-protective influence. Areas classed as of moderate influence are those draining more directly into the Pacific Ocean.

### CENTRAL COAST DRAINAGES

Coniferous forest occupies less than 8 percent of the central coast drainage area, which extends along the Coast Range from San Francisco Bay to about 20 miles southeast of Santa Barbara. The coniferous forest is largely confined to areas near the coast where precipitation is rather heavy, averaging 25 to 40 inches annually. The woodland and brush types occupy approximately 40 percent of the drainage area, in general the portions where precipitation averages from 15 to 25 inches annually. They cover the bulk of the steep Coast Range slopes.

Demand for water for municipal and domestic use is heavy. It is from the northern part of this basin, the Spring Valley development, that San Francisco obtains a large part of its water supply. Many communities depend upon wells, the water table of which is dropping, and will require new storage. In the southern part of the basin there is a shortage of water to meet the demand for domestic, industrial, and irrigation supplies.

Fires in the chaparral, brush, and forest cover in these drainages are sometimes disastrous. A record fire that occurred during the fall of 1932, resulting from carelessness of a recreationist, consumed the forest cover on more than 200,000 acres in the southern part. The inevitable silting from erosion of fire-devastated slopes will seriously threaten the permanency of the Santa Barbara and Montecito reservoirs. The seriousness of this prospect is suggested by the silting of the Gibralter Reservoir of the city of Santa Barbara that has followed fires.

In 1923 and 1925 fires destroyed the brush and small-tree cover on 40,000 acres, or 30 percent, of the 133,000-acre drainage basin of this reservoir. By 1928, sediment washed into the reservoir by erosion from the burned area amounted to 6 percent of the reservoir's storage capacity, and large quantities of sand, gravel, and boulders were piled along the streams in position to be washed down in future years. In 1932, silt deposits occupied more than 14 percent of the reservoir's original capacity. Since construction of the reservoir cost $57.50 per acre-foot of storage space, these erosion deposits have cost the city $120,750 in the 10 years since completion of the project. The loss of investment in storage in the Gibralter Reservoir, in 10 years, has been more than $3 for every acre burned. Silting from a drainage densely covered by brush is comparatively slight. The entire forested area in this basin has been classed as having a major watershed-protection influence.

### DESERT BASIN

Of outstanding importance in the desert basin, which includes much of the southeastern part of California, is the maintenance of as effective a cover as possible on the Owens Valley watershed, from which the city of Los Angeles obtains water. The east slope of the Sierra

Nevada is narrow and steep. Only a very small part of that watershed is covered by coniferous forest. A somewhat larger part of it is woodland. The principal forest trees, whitebark pine, Jeffrey pine, pinon, and juniper, grow in open stands and produce only small quantities of litter, and there is seldom a dense cover of undergrowth. Rainfall is light, ranging for the most part from 10 inches to 20 inches or slightly more at the higher elevations. The granitic soil is rather porous and ordinarily is not readily eroded. Because of these conditions most of the forested area has been classed as of moderate and some as of slight watershed-protective influence. The importance of the water supply, however, may justify classifying part of this area as of major influence.

The forested areas at the southern extremity of the Sierra Nevada, on the Tehachapi Mountains, and on the east slope of the southern coast mountains, chiefly woodland and brush lands, have been classed as of major watershed-protective influence. The flow of streams from these areas, such as the Mojave and Whitewater Rivers, is rather meager and flashy. The demand for water for irrigation and domestic use exceeds the surface supply. The deficit is made up by pumping water from wells.

The plant cover, naturally sparse owing to low precipitation and high evaporation, has been so depleted that the basin is exposed to a considerable danger of floods from torrential rains that occur fairly frequently. A storm of more than 7 inches near Tehachapi Pass in late September 1932, caused a flood that killed 15 people and did about $1,000,000 worth of damage to property. Flood discharges from the storm area are reported to have been estimated by engineers of the Los Angeles Flood Control organization to have varied from 2,000 to 5,000 second-feet per square mile. Where the rain was most intense, representatives of the California Forest Experiment Station found it washed away 4 to 6 inches of the poorly vegetated surface soil. No gullies were found on areas having a good plant cover.

### SOUTH COAST DRAINAGES

In the south coast drainage area, which lies west of the summit of the Coast Range and extends from near Santa Barbara to the Mexican border, the water-supply problem is one of the greatest in the United States. Projects planned or actually under way to provide additional supplies for the part of the basin around Los Angeles, as reported in South Coastal Basin, Bulletin No. 32 of the California State Division of Water Resources, will cost in the aggregate close to $350,000,000, exclusive of distribution systems. That report states that in the drainages of the Los Angeles, San Gabriel, and Santa Ana Rivers there are—

> * * * 57 incorporated cities, numerous urban communities not incorporated and 2,200 square miles of irrigable land or land suitable for residential development. About 2,500,000 people, or nearly 50 percent of the population of the State, live in this basin, although the area is less than 1⅗ percent of the total area of the State and only seven tenths of 1 percent of the water supply is found here. Population and irrigated area are rapidly increasing.
>
> * * * From this it may be inferred that water supply will be the limiting factor in development of the section. It is isolated and remote from other sources and to bring water to it is an engineering undertaking of the first magnitude. To amplify the local supply, the city of Los Angeles has constructed its 250-mile aqueduct to bring in Owens Valley water from the north and now proposes to extend this to Mono Basin still farther north in order to reach additional supplies.

The metropolitan water district is actively proceeding with its Colorado River project to bring in 1,500 second-feet. [Through an aqueduct more than 200 miles long] * * *.

If importations for Los Angeles City from Owens Valley be neglected, about 90 percent of all water supplies are derived from underground reservoirs underlying the valley floors on which the major part of the cities and towns and agriculture have been developed. These underground reservoirs or basins in turn get their supply by retaining a part of the wild and sudden floods of the region and a part of the rainfall which comes upon the valley floors overlying them. They regulate by natural processes the surplus waters of the wet for use in the dry years and have made the present economic development of the region possible. All plans for additional water supply propose further utilization of the underground reservoirs and control, insofar as possible, of the supplies placed in them.

* * * The water plane in practically all of these has been falling for many years past. Into some, salt water is penetrating from the ocean. Water is being pumped from below sea level in 162 square miles of the Coastal Plain, according to recent surveys. * * *

The run-off that supplies these underground reservoirs comes principally from the forest and brush covered slopes of the mountains on which annual precipitation averages about 23 inches. Coniferous forest occupies less than 5 percent of the south coast drainage area, occurring principally on the higher mountain slopes and plateaus. Practically all the steep mountain slopes are covered by chaparral, brush, or woodland, which together occupy more than 40 percent of the 11,075 square miles included in the drainages, ordinarily in a dense stand that forms a complete canopy. All the lands having such cover are classed as exerting a major watershed-protection influence.

In these drainages there are two types of vegetative cover: Dense chaparral on the slopes, and hardwood trees along stream channels. In experiments carried on by the California Forest Experiment Station, surface run-off from slopes recently burned has amounted to only 1 or 2 percent of the season's precipitation of 20 to 30 inches. Even this small surface run-off is from 2 to 30 times that from adjacent brush-covered slopes. They showed also that on a level bare surface with no run-off 60 percent of a 23-inch seasonal precipitation was evaporated, leaving about 40 percent to become a part of underground supplies. In contrast with this, an average of only 30 percent of the seasonal precipitation was evaporated from soil covered with forest litter from which no surface run-off occurred. Shrub growth and litter on slopes prevent abnormal erosion, which would otherwise become destructive. The annual run-off in streams from chaparral-covered watersheds, which stream-flow records indicate amounts on the average to from about 10 to 20 percent of the annual precipitation, in large part reaches the streams by underground seepage from slopes. In the long, dry summer period run-off is normally low, and in many streams surface flow sometimes ceases entirely.

Canyon-bottom vegetation of alders, willow, and such water-loving species, transpires very large quantities of water back into the atmosphere, and by that much reduces the surface and subsurface stream flow from the watershed, during periods of highest demand for water in the valleys. In the south coast drainages this canyon-bottom vegetation occupies not more than 5 percent of the total area, but loss of water through transpiration during long dry summers by this subirrigated vegetation is relatively very large. Much water that would otherwise be lost in transpiration in mountain canyons can be saved by piping the water through the canyons past the stream-side vegetation.

Fire danger is extreme on the steep mountain slopes. In summer the chaparral becomes almost tinder dry and fires run rapidly, as much as 12 miles in an hour, and are difficult to control. Summer fires ordinarily consume the chaparral cover entirely, leaving the steep slopes bare and exposed to rapid run-off and abnormal erosion. As previously mentioned, in experiments conducted by the California Forest Experiment Station surface run-off from soils burned clean of vegetation and litter exceeded that from similar soils with a litter cover in ratios up to 66 to 1. Erosion was about 400 times as great on the denuded soils.

The results of these studies partially explain the heavy run-off from recently burned canyons in southern California which valley residents often attribute to "cloudbursts." The Burbank flood of 1928, for example, followed a fire of 1927 which burned over 704 acres of the watershed above this town. With only 1.07 inches of rain in 3 hours, but with a maximum intensity of 1.70 inches per hour for about 10 minutes, surface run-off was three times as great as on adjacent unburned canyons. Between 25,000 and 50,000 cubic yards of eroded material was swept off the burned watershed, while no noticeable erosion took place on adjacent unburned canyons.

Chief Engineer E. C. Eaton of the Los Angeles County Flood Control District is quoted in the bulletin Forestry in the State-Wide Water Plan as follows:

> Intense rains falling on a brush-covered watershed washed down only 400 cubic yards of debris per square mile, while the corresponding amount on adjacent burned-over areas rose to 12,000 cubic yards.
>
> Even with the controlling influence of 300 check dams per square mile on the burned area, the detrital material still amounted to 7,000 cubic yards. It is further important to note that the brush cover not only proved to be a strong check on the debris movement, but that it also effectually functioned in reducing the surface run-off. With 1.36 inches of rain per hour the burned-over area gave 1.01 inches in surface run-off while the area covered with brush produced only 0.42 inches. It follows that on the burned-off area only 0.35 inches of water were available for percolation * * * in contrast to 0.94 inches of water on the unburned area.

Such erosion debris rapidly impairs the permanency of flood-control and other reservoirs. Eaton, in discussing the Los Angeles flood-control district in the bulletin South Coastal Basin, points out that mountain fault lines limit the number of available reservoir sites and that construction on these sites would be costly.

While expenditures for fire control are heavy, practically nothing is being spent for restoration of cover. Intensive studies are warranted to determine economical means of rapidly reestablishing a vegetative cover and possibilities of replacing some of the highly inflammable species of chaparral with species more resistant to fire. The California Forest Experiment Station has made an important start in studying methods of revegetating the great cuts and fills of mountain highways in southern California. Autumn sowing of winter wheat and of seed of sunflower and native shrubs in contour furrows reinforced by cuttings of willows and elder, although rather costly, has proved very effective. This mixed vegetation, developing rapidly, maintained the treated slopes practically intact, while adjacent untreated slopes gullied at the rate of 800 cubic yards per acre during one winter and required heavy filling to restore them to safe grade.

## CLASSIFICATION OF FOREST AREAS ACCORDING TO INFLUENCE

Of the 29,780,000 acres of forested land within the California drainages, about 21,056,000 acres has been classified as of major influence in protecting watersheds, that is, in regulating run-off or reducing soil erosion, or both. As pointed out in the foregoing, this acreage of major influence occurs chiefly in the foothill and mountain areas of the Sierra Nevada and along the Coast Range. The mixed conifer, woodland, and brush cover of the Sierra Nevada and its higher foothills, the redwood and Douglas-fir mixtures and dense brush types of the north Coast Range (with the exception of a narrow strip near the coast north of San Francisco Bay), and the redwood, Douglas fir, and other conifer cover and dense brush of the central Coast Range, all are considered to exert a major watershed-protection influence. All the forests of southern California, being chiefly chaparral and woodland on the lower slopes and mixed conifers (Jeffrey pine, sugar pine, Coulter pine, white fir, incense cedar, juniper, and piñon) on limited areas at elevations greater than 4,000 or 5,000 feet, have likewise been classed as of major influence. These forests differ widely in respect to rainfall, vegetative composition, soil, and underlying geological structure.

Approximately 3,736,000 acres of forest area has been classified as of moderate watershed-protective influence. This includes the narrow strip of whitebark pine and Jeffrey pine forest and piñon-juniper woodland on the abrupt east slope of the Sierra Nevada facing Owens Valley. It is classed as of moderate rather than major influence chiefly because of the scantiness of the rainfall and the porous nature of the granitic soil. The other large area of moderate influence is that along the coast north of San Francisco Bay occupied by dense stands of redwood and Douglas fir. On this area the forest effectively protects the soil against erosion and has a material influence in retarding the run-off of the heavy precipitation. After logging or burning, forest cover is rapidly reestablished. Erosion damage is ordinarily very much localized, and high water is seldom serious. Furthermore, the water supply is adequate to meet all demands.

Approximately 4,988,000 acres in the northern part of California and in the adjacent part of Oregon included within the California drainages has been classed as of slight watershed-protective influence. This large area of forest is made up chiefly of ponderosa pine, white fir, and other coniferous species growing upon volcanic hills and ancient lava flows. Here the precipitation percolates so promptly through the porous soil and lava into underground channels that very little surface run-off occurs and abnormal erosion is almost negligible. Such rivers as the McCloud and other tributaries of the Pitt River are fed by large springs, which are in fact a bursting forth of underground streams of considerable size.

## WATERSHED-PROTECTION REQUIREMENTS AND HOW THEY ARE BEING MET

The principal factors modifying or disturbing watershed-protective forest cover within the California drainages are fire, grazing, and lumbering. The State watershed committee in its report Forestry in the State-wide Water Plan pointed out that—

hot, dry summers favor intense and widespread burns which leave watershed surfaces bare and ash-covered, exposed to the full effects of the wash of torrential fall and winter rains.

During the 3-year period 1928–30, inclusive, 7,957 forest and brush fires occurred in California and burned 2,193,114 acres, the committee states, adding "Unfortunately these fires are, in the main, set by owners of land and local residents * * *." Another serious source of fires has been carelessness on the part of some of the recreationists who visit California's forests by the millions every year.

While most of the fires occur on foothill woodland and brush areas, large areas of virgin forest and of cut-over land are still burned every year. Fire protection is improving both on Federal lands and on private lands protected by the State. Climatic difficulties, however, require intensification of suppression activities by the Federal Government on the national forests, national parks, and Indian reservations and by the State on State and private lands. The State division of forestry is charged with the duty of protecting private lands from fire. As stated by the honorary watershed committee:

> * * * With meager funds and, frequently, lukewarm public support, it has attempted to meet its obligations through educational means, endeavoring to create popular sentiment for the prevention and control of fires. By slow stages, it is developing a machinery for fire protection covering the territory outside the national forests. It must be noted that the owners of forest and woodlands under State protection often are interested in other than the water crop of which they themselves are not the direct beneficiaries. Under these conditions, frequently the type of occupancy and use seriously impair the watershed values. This conflict in use and values must be weighed and judged in the light of the relative need for timber, forage, recreation, and water crop. Under sound forest management, such conflicts will be avoided and all of the inherent values of forest lands safely and wisely utilized. Larger State expenditures will be needed in order to carry out an adequate protection program.

Excessive use of range feed once was common over a large part of California's forested areas. Grazing has been practically eliminated from the steep brush-covered slopes within the national forests of the south and central coastal basins. Efforts have been made, also, to adjust grazing to the quantity of feed available on all national forest lands within the California drainages that are still open to grazing. With long dry summers, however, restoration of depleted cover has been slow. On private forest lands, particularly in the foothills, heavy grazing use and the common practice of burning with a view to opening up brushy areas or improving the forage have seriously impaired the watershed values of extensive areas.

In the past destructive logging and the broadcast burning accompanying it were a menace to watershed values. Broadcast burning following logging has been practically abandoned, and logging practices have been made less destructive by substituting tractor logging for high-lead skidding with heavy machinery. As a result timber stands are being left in better condition for protection of watershed values.

The national forests of the California drainages contain 13 million acres of forest land, approximately one third of the total forest area in these drainages. Watershed protection has been given careful attention in national-forest administration. In the management of timber and range numerous curtailments of use have been made

in order to safeguard water resources more fully. Enough trees are left in logging to afford satisfactory reforestation and to safeguard watershed values. The subordinate vegetation in the forest is in general improving under grazing regulation. Further strengthening of the fire-control program will be necessary. Within the national parks, grazing and timber cutting are not permitted and a satisfactory watershed cover is being maintained except as it is depleted by fire.

On the 966,000 acres of forest land within the unappropriated public domain, conditions are far from satisfactory. Much of the herbaceous and shrubby vegetation is heavily grazed. Fires are set on these lands just as on private lands, exposing the soils to erosion. This area should be given a status that will insure proper management.

The situation on private lands, especially in the foothills is such that the public should acquire about 10,000,000 acres in these drainages, 5,000,000 acres of which is in commercial timber types and 5,000,000 acres in noncommercial forest types in the foothills.

Approximately 75,000 acres of land in critical condition should be planted to trees and another 100,000 acres seeded to herbaceous plants in order to more effectively safeguard watershed values. If practical methods can be developed for planting trees or shrubs on the depleted foothill areas the reforestation program should be greatly expanded.

## COLORADO RIVER BASIN

The outstanding watershed problems of the Colorado River basin are (1) supplying adequate water for irrigation, power, and domestic use, (2) controlling erosion, and (3) reducing damage from local floods. As is shown by figure 12, the basin includes portions of California, Nevada, Arizona, New Mexico, Utah, Colorado, and Wyoming. The perennial flow of the Colorado River and its main tributaries originates almost entirely on the higher mountain areas, nearly all of which are forested or above timber line. Most of the sediment carried by the main river and its tributaries comes from erosion of the lands at the lower elevations, which are largely nonforested, or from the scouring out of channels. Large areas of forested land, also, have soils that are readily eroded if the protecting vegetative cover becomes depleted. The intensity of the scouring of channels is greatly increased by the soil and other erosion debris washed from slopes. Local destructive floods most commonly originate at medium or low elevations, often on depleted forest areas.

### EXTENT AND WATERSHED-PROTECTION VALUE OF FORESTS

Of the 242,000 square miles of the Colorado River Basin within the United States about 70,422 square miles (45,070,000 acres), or nearly 29 percent, is forest land. Approximately one fourth of this is occupied by coniferous forests, largley commercial timber, made up principally of rather dense stands of spruce, white fir, or lodgepole pine at the higher elevations and of more open stands of ponderosa pine or Douglas fir, with an understory of herbs and shrubs, at intermediate elevations.

The aspen-brush type, predominantly aspen, occupies about one tenth of the forest area. In this type undergrowth normally is fairly dense, and small intermingled areas of brush and grassland occur.

The mountain brushland type, prevailing mainly on slopes at elevations below those supporting good stands of ponderosa pine, covers more than one fifth of the forest area. In this type oak brush is the most common species.

Practically throughout the basin, the coniferous, aspen-brush, and mountain brushland types have been classed as of major watershed protective influence. By retarding snow melt, and by facilitating the absorption of snow and rain water into the soil, they reduce the

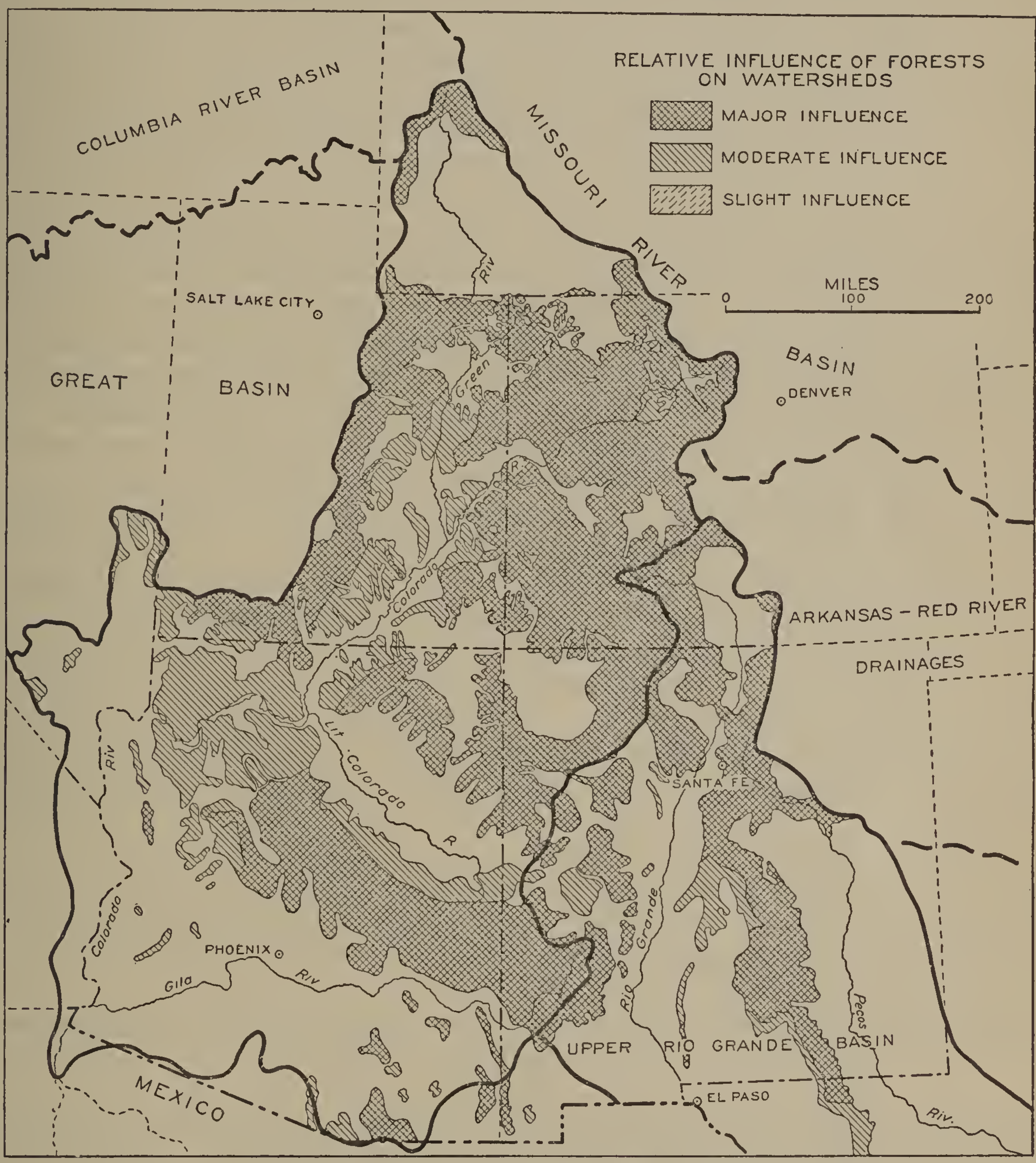


FIGURE 12.—Colorado River Basin and portion of upper Rio Grande Basin.

crests of floods resulting from snow run-off, aid in maintaining a sustained flow of water in springs and streams, and protect the soil against abnormal erosion. These functions are especially important on steep, rugged mountain slopes having a normally scant soil layer or soils of sedimentary origin and having an average annual precipitation of about 20 inches to 35 inches or more, much of which comes as winter snow and tends to run off rapidly in the spring unless the slopes are well protected with vegetation. Where these forest types occur on undulating or level plateau areas from which run-off normally is not rapid and on soils derived from lava or basalt that

are not readily eroded, they are considered to exert a moderate watershed protective influence. A level forested area of porous volcanic soil about 45,000 acres in extent on the Colorado Plateau of northern Arizona is classed as having practically no watershed-protection value.

The pinon-juniper woodland, occupying about half the forest area, occurs principally near the lower limits of forest growth. The quantity of usable water obtained from this type is small. At these levels snow seldom accumulates. Most of the summer rains are so mild that there is little surface run-off from them and their effect on the water supply is negligible. Semitorrential rains are rather common and sometimes reach the proportions of "cloudbursts." Such storms cause very rapid run-off accompanied by severe erosion especially on steep and unstable slopes that are inadequately protected by a plant cover. In the woodland type there is normally but little undercover on slopes and the tree cover itself is seldom dense enough to form a closed canopy and heavy litter. This cover, such as it is, should be maintained and improved where it is depleted. As previously mentioned, studies by the Southwestern Forest and Range Experiment Station have indicated that on most of the soils on which the woodland type occurs in Arizona, which are fairly representative of woodland soils throughout the basin, a stand of herbaceous and shrubby vegetation can be maintained which with the trees is sufficient to check run-off and abnormal erosion. Growth conditions are so severe that the protecting cover can easily be seriously depleted by overgrazing, fire, or too heavy cutting.

Woodland areas have been classed as of major watershed-protection influence if their potential forest cover would aid materially in checking run-off and erosion on slopes, a heavily silt-laden run-off from which is resulting, or would result in undue damage to irrigation developments or other property. Woodland areas the topography of which is level, rolling, or moderate, and the soil of which is not readily eroded, have been classed as of moderate watershed-protection value.

Of the total forested area within the Colorado River Basin approximately 36,196,000 acres has been classed as of major watershed-protection influence, 8,829,000 acres as of moderate influence, and 45,000 acres as of scant influence.

## WATER SUPPLY FOR AGRICULTURE, POWER, AND DOMESTIC USE

In the Colorado River Basin agriculture, the most important industry, is almost wholly dependent upon irrigation. More than 2,700,000 acres of land is already under irrigation from Colorado River water. Rural homes and villages dot the irrigated valleys, and large urban centers have gained added impetus in growth from irrigation farming. The irrigated portion of the Salt River Valley, for example, contains one fifth the population of Arizona. In the irrigated Imperial Valley of southern California unusually large values are present, and in the upper portion of the Colorado River Basin valley after valley owes its present development to irrigation. The United States Bureau of Reclamation has estimated[69] that the irrigated area within this basin could be expanded to 6,930,000 acres. The

[69] S.Doc. 142, 67th Cong., 2d sess., 1922.

future prosperity of the basin depends in large part upon safeguarding the irrigation-water supply and the storage reservoirs. While the main irrigation projects have developed large storage facilities, the small enterprises in the mountain valleys have only slight storage facilities or none; hence their effectiveness depends upon sustained stream flow throughout the irrigating season.

Numerous power plants and many communities throughout the basin are dependent upon sustained stream flow to meet their water needs. Of outstanding importance to the future of southern California is the Hoover Dam project. This stupendous project with its 700-foot dam will impound 30,500,000 acre-feet of water, irrigate more than 2,000,000 acres, develop more than $6,500,000 worth of power annually, and furnish the supplementary water supply needed for Los Angeles, San Diego, and other southern California cities and communities.

The flow of the Green River and its tributaries in Colorado, Wyoming, and Utah illustrates rather clearly the fact that the perennial flow for sustaining irrigation, power, and domestic supplies, comes principally from the higher mountain areas. On that watershed about 60 percent of the 18 to 30 inch yearly precipitation comes as snow, which above 7,000 or 8,000 feet elevation accumulates from October until mid-April. During the late spring months heavy surface run-off from this melting snow swells the streams to a normal high-water stage. Stream-gage records of the United States Geological Survey show that 74 percent of the annual run-off occurs in the 4-month period April to July. The low-water stage is maintained rather uniformly through the remainder of the year by the flow of hundreds of springs scattered throughout the higher mountain areas and by that of many mountain lakes. Summer rainfall at any elevation, and snowfall and springs at low elevations, make only a relatively small contribution to stream flow. The snowfall at high elevations and the conditions under which its transformation into water takes place are the important factors in water production.

## EROSION

In the Colorado River Basin abnormal erosion, since white settlement has removed from 1 to 7 inches of the fertile topsoil from extensive slope and even plateau areas, is still occurring on far too high a percentage of the forest land, and is cutting out valuable alluvial soil along nearly all water courses below the dense timber belt.

The most serious erosion conditions on forest lands are found in the piñon-juniper, ponderosa pine, and mountain-brush types, especially on the heavy clay or adobe soils and sometimes on sandy loams. These soils are ordinarily deficient in humus, are more or less alkaline, do not readily absorb water, support only a thin stand of vegetation, and readily disintegrate when thoroughly wet. Thus under the influence of semitorrential rains, if inadequately protected by vegetation, they are eroded at a rapid rate. The serious effect of vegetative depletion is exemplified by the extensive areas (largely privately owned) in the pine forests near Pagosa Springs, Colo., that were logged beginning in the nineties and continuing until about 1920. The timber was heavily cut and the areas have been overgrazed, mainly by sheep. Throughout these areas there is excessive sheet and gully erosion, in practically all stages of intensity and activity.

Erosion has greatly increased in practically all the tributary watersheds since settlement. Much of the piñon-juniper type is still in the unreserved public domain, open to unregulated grazing use. Wherever water is available for livestock this land is invariably overgrazed and badly abused; furthermore, cutting and fires are widespread. Vegetative depletion has accentuated the erosion and, if we may judge from C. K. Cooperrider's studies of the Southwestern Forest and Range Experiment Station in the woodland and brush types of Arizona, the loss of soil productivity through erosion, in turn, has made maintenance of even the reduced vegetation more difficult. Thus is established a trend toward destruction that is difficult to check.

In the Verde River Valley near Jerome, Ariz., smelter fumes have killed tree growth on a considerable area. Where the grass and other vegetation, as well as the trees, have been practically eliminated erosion has become extremely serious. Over most of the affected zone, however, the soil is still protected by a good growth of grass.

At the higher elevations the soils are gravelly loams, sandy loams, or sandy silt loams. They are fertile, dark, and high in organic content. Typically they are rather thinly deposited on steep slopes, but they attain a fair depth in depressions. They support abundant forest cover and are relatively free from erosion where the cover is not depleted, although they receive the greatest precipitation occurring in the basin. Even heavy clay soils under the more humid conditions at the higher elevations produce fairly abundant plant cover which affords them good protection, although these soils erode readily when the vegetation is depleted or on areas where they have never reached stability.

According to an extensive erosion survey made by the Forest Service on the Colorado River watershed above Grand Junction, Colo., areas of heavy erosion compose 33 percent of the watershed, areas of moderate erosion 27 percent, and areas of little or no erosion 40 percent. As a general rule the heaviest erosion occurs in the nonforest types or in piñon-juniper woodland. Moderate erosion occurs in piñon-juniper, brushland, and nonforest types where cover has been somewhat depleted. Little or no erosion occurs on well-forested areas or on non-forested areas where a good vegetational mantle is maintained.

One of the most serious effects of erosion is the silting which threatens to shorten the usefulness of reservoirs. The Roosevelt Reservoir on the Salt River of Arizona already has great silt banks in its head. Portions of these are cut away and the material washed closer to the dam by each big flood; then, as the lake refills, new deposits are added. Such silt is made up of material cut from watercourses and soil from slopes where the vegetative cover has become depleted. According to settlers, serious destruction of the vegetative cover was general 30 to 40 years ago. With drought conditions prevailing during many of the last 15 years, the slopes are but slowly revegetating.

Fortier and Blaney estimate[70] that the Colorado River carries 137,000 acre-feet of silt annually past the Hoover Dam site. If this continues the reservoir will fill with silt in about 220 years, and its

[70] Fortier, Samuel, and Blaney, Harry F. "Silt in the Colorado River and its Relation to Irrigation." U.S. Dept. of Agri. Tech. Bul. 67, 1928.

value for storage of flood water for use in extended drought periods will be greatly impaired much sooner. Losses of investment in engineering works from silting may be liquidated to the satisfaction of financial interests and additional dams may be built to suffer a similar fate, but the consequent decay of communities dependent upon irrigation cannot be so liquidated.

## FLOODS

Closely related to rapid run-off from slopes depleted of vegetation and to abnormal erosion are destructive summer floods. In the Colorado River Basin such floods occur, often in intermittent stream courses, mainly as a result of heavy rains. High water results normally each spring from snow melt, sometimes assuming destructive proportions in the lower reaches of the river and in its main tributaries. Those spring flows seldom become destructive in the smaller tributaries except in the occasional year when heavy warm rains produce unusually rapid snow melt. The destructive flash floods which follow semitorrential summer storms originate in greatest number and greatest intensity in the piñon-juniper and mountain-brush types and on nonforested areas at lower and intermediate elevations where the vegetation is thin. In 1921, for example, severe floods largely from such types occurred in the Dolores River, Henson Creek, Lake Fork, and East and West Rifle Creeks of Colorado following a 4-day rainy period with a maximum precipitation at Ashcroft, near Aspen, Colo., of 2.5 inches. The Dolores River washed out many miles of railroad track, and Henson Creek caused considerable property loss at Lake City by cutting a new channel through part of the town.

Price River has had numerous floods originating on the higher mountain forested areas. In 1927, for example, floods transporting immense amounts of debris and silt damaged railroad and mine property, highways, bridges, irrigation works, city water supply, and farm crops to the extent of at least $500,000. The watersheds of Gordon Creek and Willow Creek, the two tributaries which contributed most of the flood waters, had suffered a heavy reduction in plant cover on forested areas through extreme grazing use. In contrast the drainage of Miller Creek, a nearby tributary comparable to Gordon Creek, has been protected from excessive grazing use since a time several years prior to the 1927 flood, and maintains a relatively abundant ground cover even in the nonforested portions. It shows almost no abnormal erosion or channel cutting, while Gordon Creek is newly channeled to a depth of 50 feet and a width of 100 feet.

Floods have been a source of great loss to the agricultural industry. The valley bottom lands most suitable for irrigation have been subjected to inundation and debris deposit or have been cut away by flood waters. A number of small reservoirs have been rendered useless by silting or the dams have been washed out. Silting of irrigation ditches and loss of headgates and diversion dams have occurred to some extent on every stream in the region.

Conditions on the Paria River, in southern Utah, present an outstanding example. Approximately two thirds of the Utah portion of this watershed, i.e., 11 or 12 townships, is occupied by forests, chiefly of the woodland and mountain-brush types, with

ponderosa pine near the headwaters. Paria was first established in 1871; by 1884 it had grown to a community of 107 permanent residents, all living on irrigated farms along the river. Floods, beginning in 1885, have channeled the valley bottom. The shifting bed of the river is now only a sandy wash, in some places a quarter of a mile wide. At Paria there have been no permanent residents since 1925, and the land still arable does not exceed 60 acres. At Henrieville and Cannonville, two of the three remaining settlements on the river approximately one third of the land capable of cultivation in 1880 has been cut away. The third settlement, Tropic, has suffered heavy, but unestimated, losses of farming land.

Kanab Creek, near Kanab, Utah, further demonstrates the effect of floods and erosion. This stream began to erode its bed about 14 years after the settlement of Kanab in 1870. It has continued to entrench until the stream bed in places is now at the bottom of a 60-foot gully 200 to 300 feet wide. The gullying extends through the woodland, which covers rather large areas of the watershed above Kanab, to the heads of tributaries in the mountain-brush type, which now have new channels 4 to 6 feet deep. The eroded material has been carried downstream, filling the Kanab Reservoir with silt and contributing to the silt load of the Colorado River.

## WATERSHED-PROTECTION REQUIREMENTS

That the accelerated erosion in southern Utah and adjacent States is not due to climatic change alone is evidenced by the fact that the channeling did not start in all valleys at the same time. In some valleys it is much more recent than in others, and a few valleys are still uneroded.

The greatest damage caused by controllable factors to plant cover as a protection for watershed values on the Colorado River has come from overgrazing, fire, and excessive timber cutting, named in the descending order of importance. Nearly all the lands of the basin have value for grazing or timber production or both and are subject in varying degrees to damage by fire. Adequate watershed protection in the basin, therefore, requires proper range and timber management and fire protection. Research results indicate the desirability of controlling grazing, timber cuttings, and fire so as to make possible the maintenance of a plant, litter, and soil cover approximately equal to that which would be brought about under complete protection from use and fire.

Especially on forest areas at lower elevations, restoration of cover is essential. Range research of the United States Forest Service indicates that where soil and moisture conditions are favorable and a seed supply of suitable native plants is present, under careful management the cover can ordinarily be restored on moderately depleted areas in from 3 to 5 years. Where soil and vegetative depletion have reached an advanced stage, artificial restoration will be necessary if a satisfactory cover is to be reestablished within a reasonable period. This would take the form of planting trees on the more favorable sites and herbaceous plants on those somewhat less favorable. On the latter sites establishment of forest trees is so uncertain and growth is usually so slow that it is difficult to establish a stand of trees sufficient in itself to afford the necessary watershed protection.

## CONDITIONS ON LAND IN VARIOUS TYPES OF OWNERSHIP

In general it may be said that watershed requirements are being met reasonably well or are in process of being met on the 21,913,000 acres of forest lands in the Colorado River Basin included in national forests. Fire protection is afforded, range conditions are improving under the system of management in effect, and timber cutting is regulated. Some areas that were seriously depleted when the national forests were created are not yet in satisfactory condition to safeguard watershed values. In southern Utah, for example, where the balance between the forces that build up soil and those that tear it down is extremely delicate, many national-forest areas are still affected by abnormal erosion. Lumbering, fire, and insects have been partly responsible, but the major factor has been the extreme grazing use to which the plant cover was formerly subjected. Although forage conditions are generally better within the national forests than elsewhere in the locality, from a run-off and erosion standpoint large areas within the national forests are still in a critical condition. Likewise within the national forests in the important Salt and Gila River drainages in Arizona and New Mexico, there are areas where abnormal sheet and gully erosion have not yet been corrected. These are chiefly granitic and clay soils from which the top layer has been removed and on which, because of normally low rainfall, it is difficult to restore a satisfactory cover.

Generally, however, within the national forests of the Colorado River Basin the forest cover is in a satisfactory condition for erosion control and for water delivery. Research is justified to determine further possibilities for the discharge of water in maximum quantities, at times when it is most needed, and in a condition largely free from undue silt burden.

On the national parks in the Colorado River Basin timber cutting and the grazing of domestic livestock have been materially restricted or eliminated, which should facilitate restoration of herbaceous and shrubby vegetation within these areas and increase their protective value. On the Kaibab Plateau, however, some overgrazing of the underbrush by deer is occurring which, if continued, may adversely affect the watershed-protection values of the forest.

The seriousness of erosion within Indian reservations of the basin is emphasized by Lee Muck, Percy E. Melis, and George M. Nyce in their report to the Committee on Indian Affairs of the United States Senate entitled "An Economic Survey of the Range Resources and Grazing Activities on Indian Reservations".[71] This report reads in part as follows:

> * * * It can be said without exaggeration that the control of erosion presents a grave problem in the management of every Indian reservation in both New Mexico and Arizona. On many reservations the situation is quite acute and in every case the principal contributing factor has been overgrazing. When the soil of this territory has been laid bare by overgrazing it is peculiarly subject to erosion, and the climatic conditions, particularly the prevalence of sudden and violent summer storms, tend to further aggravate the condition. When these soil and climatic conditions are considered in connection with the excessive number of stock that have for years been grazed on these areas, the disastrous progress of erosion in this region is readily understood. * * *

[71] Survey of Conditions of the Indians in the United States. Part 22. Hearings before a subcomittee of the Committee on Indian Affairs, of the United States Senate, 71st Cong., 2d sess., 1932.

Owing to the stand of coniferous timber occurring on the higher elevations of this region, the severity of erosion has been considerably lessened, but it is obvious to even the lay observer that the removal of this protective forest would result in even a more serious condition than is now so prevalent on the lower slopes. * * *

Severe overgrazing within the timbered areas has been observed by the foresters of the Indian Service throughout the southwest region and the destruction of young growth through the activities of hungry sheep and goats is a matter of common occurrence. The continuance of this overgrazing to this degree will eventually result in the destruction of the forest and the serious erosion of the present forested areas.

Efforts are being made to establish management that will overcome the present unsatisfactory watershed conditions on the 8,493,000 acres or so of timber, woodland, and mountain brush lands in Indian reservations in the basin.

The most serious erosion and flood situations within forested areas on the Colorado River watersheds exist on the 5,998,000 acres of forested land in the unreserved public domain. Conditions are especially bad in the piñon-juniper woodland, the principal forest type. The public domain should at once be placed under public administration. On these lands and on much of the State and private land intermingled with them, unregulated grazing has led to excessive depletion of the undergrowth. Trees and even brush have been heavily cut, especially around mining camps, and forest fires are seldom controlled. Administration of the Federal lands that will restore a satisfactory forest cover is essential.

Conditions on most private lands in the basin are little if any better than those on the public domain. Overgrazing has seriously depleted the herbaceous cover, fires ordinarily burn uncontrolled, and the cutting of trees is seldom managed with a view to regeneration of the timber cover. Rapid run-off of water and abnormal erosion accordingly are prevalent. Education of private landowners as to the effects of abuse of watersheds is badly needed. Public acquisition of about 2,800,000 acres of lands having a major influence will probably be necessary in order to restore forest cover conditions that will afford the necessary watershed protection.

Within the public forests 150,000 acres of devastated land should be reforested and artificial revegetation with soil binding grasses or shrubs is needed on 200,000 acres.

## UPPER RIO GRANDE BASIN

The upper Rio Grande Basin, including the Pecos River drainage (see figs. 6 and 12) has an area of about 169,000 square miles in western Texas, New Mexico, and southern Colorado, and an area of more than 50,000 square miles in northern Mexico. Approximately 27,281 square miles (nearly 17,460,000 acres), or 16 percent of the portion of the watershed within the United States, is classed as forest land.

### WATERSHED PROBLEMS

The most important watershed-protection problems in the upper Rio Grande Basin are accelerated erosion, the destructive flood menace, and the demand for adequate water for irrigation.

This basin was settled by the Spanish as early as the sixteenth century. While the settlements were mainly concentrated in the

nonforested valleys some, including the capital of the territory under Mexican administration, were within the forest. There is little question that the protecting vegetation near these settlements was partly destroyed in the early nineteenth century. Destruction of vegetation sufficient to menace watershed values, however, apparently did not occur over extensive areas until sometime after the Civil War, following introduction of large herds of cattle and sheep. Mining and other settlement resulted in extensive fires and some devastation of timber stands.

Following deterioration of the grass and other protecting vegetation, rapid run-off of rainfall removed much of the surface soil over enormous areas through sheet erosion, materially reducing the productivity of the land. For example, an erosion survey of the drainage above the Elephant Butte Dam made in 1931 by C. K. Cooperrider and B. A. Hendricks of the Forest Service disclosed that 35 percent of the area is being eroded seriously, 40 percent moderately, and the remaining 25 percent slightly. While a much higher percentage of nonforested than of forested area was found to be seriously and moderately eroded, the total forest area thus affected was large.

The rapid run-off from these depleted and eroded lands has formed an extensive system of gullies, small near the upper parts of slopes but often 10 to 30 feet deep and several hundred feet wide in main stream courses. Such a system of gullies is extremely efficient in concentrating water from torrential rainfall into flood proportions. The water thus accumulated, heavily charged with soil and other debris, continually adds to its burden and its destructive power by erosion from channel banks as it flows through the alluvial valleys.

Floods and erosion combine to cause serious losses almost every year. Excessive high water resulting from melting of snow, and from torrential summer rains, cut away valley farm lands, wash out railroad and highway bridges, endanger lives, and silt up reservoirs, other irrigation works, and stream channels.

Kirk Bryan, on the basis of early records and of field surveys, has outlined [72] as follows the trends on the Rio Puerco, in New Mexico. A small channel existed before 1885. While the stream banks may have been as high as 20 to 30 feet in places, in other places they were so inconspicuous as not to be mentioned by early surveyors and explorers. The river was subject to numerous floods of short duration and to occasional floods of great magnitude which overflowed the valley floor. Beginning in the late eighties, accelerated erosion has cut an arroyo in some places nearly 50 feet deep from the mouth of the Rio Puerco almost to its head. The present channel has an average depth of 28 feet and an average width of 285 feet. The continuing erosion, deepening and widening the channel, has destroyed much farm land and caused the abandonment of six small settlements including Los Cerros, San Ignacio, and San Francisco. Silt to the amount of 9,400 acre-feet a year, on the average, has been poured from the Rio Puerco into the Rio Grande for the past 42 years.

Because of floods the railroads and the State and county highway organizations are forced to expend considerable sums for special roadbed drainage and for protection works to prevent destruction of the

[72] Bryan, Kirk. Historic Evidence on Changes in the Channel of Rio Puerco, a Tributary of the Rio Grande in New Mexico. Jour. Geology, v. 36, no. 3 : 265–282. 1928.

tracks, and to replace washed-out bridges, culverts, and parts of highways and trackage.

The 1929 floods, largely from the Rio Puerco and Rio Salado, according to the report of the New Mexico State engineer caused a loss of $950,000, excluding damage to roads and railroads. Thousands of acres of farm land were buried under an almost worthless layer of clay and sand, and the town of San Marcial was practically wiped out by flood waters and by sand deposits as deep as 7 feet.

Silt deposits resulting from erosion and floods have become so great in the Rio Grande channel near Albuquerque that work has been started on a drainage and flood-control project which the chief engineer of the conservancy project estimates will cost $10,300,000 when complete. In 17 years about 337,939 acre-feet of silt has been deposited in the Elephant Butte Reservoir, the storage basin for the Rio Grande project of New Mexico, Texas, and old Mexico, according to estimates of the United States Reclamation Service, reducing its capacity by nearly 13 percent.

Since erosion, once started, accelerates and increases cumulatively in seriousness until it is checked, it is reasonable to expect greater flood damage and greater silting in the future unless corrective action is taken.

Erosion and flood problems exist on both the forest and the range lands of the Rio Grande Basin. Although they are more serious on the range lands which make up the larger part of the basin, this report is concerned only with the situation on forest lands.

Agriculture in the Rio Grande Basin is mainly dependent upon irrigation. Irrigation developments in the small mountain valleys aggregate several hundred thousand acres. The most extensive irrigation, accompanied by important urban developments occurs along the Rio Grande and the Pecos Rivers and their main tributaries where reservoirs have been established to impound flood waters and the permanent run-off from the mountain forested areas. Existing erosion conditions threaten the permanency of irrigation agriculture.

## EXISTING WATERSHED CONDITIONS BY FOREST TYPES

Erosion and rainfall run-off conditions are in general more unsatisfactory in the woodland type than in any other forest type in this basin. The woodland type, the lowest type as to elevation, consists of orchardlike, or occasionally rather dense, stands of juniper, pinon, and oak with an understory of grasses, other herbs, and brush. Originally such vegetation and the litter accompanying it covered up to 50 percent, or occasionally more, of the soil surface. In open stands of this type the litter cover is ordinarily slight and the understory vegetation is an important supplement to the trees in watershed protection. Studies made by C. K. Cooperrider of the Southwestern Forest and Range Experiment Station in Arizona, the semiarid climate of which is comparable to that of the Rio Grande Basin, have shown that the herbaceous vegetation of the woodland type varies in quantity as between years of high rainfall and years of drought, but that a vigorous vegetative stand covering as much as 35 percent of the soil surface usually prevents excessive run-off and protects the soil against abnormal erosion. With annual rainfall averaging only 14 to 20 inches, normally dry springs, extreme droughts sometimes lasting several

years, high evaporation, and soils which lose fertility readily through their tendency to be eroded easily, nature's balance for maintaining he plant cover is delicate.

Over extensive woodland areas the loss in plant cover has averaged one half to three quarters, as shown by the erosion survey of the watershed above Elephant Butte Dam. Such destruction is largely the result of overgrazing since the drainage was settled by whites, although locally, extreme changes have resulted from timber cutting. In some instances an increase in tree reproduction has failed to offset declines in grasses and weeds. Sheet erosion is widespread, and wherever this has reached an advanced stage gullying also is severe. Rapid soil wastage is attested by remains of grass clumps, sagebrush, and tree reproduction on soil pedestals often a foot or more in height, exposure of large tree roots, and the formation of straight-sided gullies even on slopes of low gradient. The loss of fertile top soil and of its moisture-holding capacity has intensified the deficiency of soil moisture, which at best severely limits the density of vegetation.

Such conditions prevail on most of the woodland areas in the unreserved public domain and on far too many private holdings, including many of the large Spanish land grants. On the national forests, efforts to improve conditions through regulating grazing and timber cutting have been in progress for 20 to 25 years; on many of the woodland areas, however, destruction of vegetation and soil had reached such a serious degree, particularly on readily erosible clay soils, that improvement of plant cover has been extremely slow and has not yet stopped the abnormal erosion.

Woodland areas have been classed as of major watershed-protective influence if erosion resulting from depletion of their cover would endanger irrigation or other values in valleys below. Most areas in this type where erosion would chiefly affect the productivity of the forest soil, and have little influence on other values, have been classed as of moderate watershed-protective influence.

Within the forest types above the woodland, watershed conditions are in general reasonably good. The greater part of the water supply for irrigation and for municipal use in this drainage comes from these forested mountain lands, largely as stream flow from immediate surface run-off of snow water and from springs fed by percolated snow water. The forest types which produce lumber, the ponderosa pine at intermediate elevations and the spruce at higher elevations, exert a major watershed-protective influence through retarding snow melt and run-off of snow and rain water, aiding in absorption of moisture, and protecting the soil against erosion. In the ponderosa pine type the tree stand is rather open but the litter cover and undergrowth of grasses, other herbs, and occasional shrubs, where not depleted, is normally sufficient to afford good watershed protection. In the uncut spruce forests the stand of timber is generally rather dense and, with its heavy duff, serves admirably in watershed protection. In these types lumbering, overgrazing, and fire usually decrease the watershed-protective values of the forest cover.

Most of the commercial timberland is within the national forests. Here deterioration of the protective cover has been or is being checked in most instances. Marks of past erosion still remain, but numerous eroded areas have been restored to cover conditions capable, under effective regulation, of arresting abnormal erosion. For example, on

the ponderosa pine area at the head of Senorita Canyon near Cuba, N.Mex., on which as lately as 20 years ago low vegetation was rather scanty and erosion was very active, as a result of grazing regulation the slopes are now well carpeted with bunch grasses, sheet erosion is practically stopped, and the cutting in gullies is checked. Sides of gullies formerly 1 to 3 feet deep have assumed an angle of repose and the grasses that have come in on them have stabilized the soil.

On many private commercial timberlands, timber cutting and grazing have been, and are continuing to be, severe. The vast timbered area at the headwaters of the Chama River comprised by the old Tierra Amarilla Grant, for example, has been cut over within the last 40 to 50 years, and this cutting has been followed by severe grazing. As a result much of the area formerly forested is now brush land or low-density grassland. Observations by members of the Forest Service extending over the last 20 years indicate that these changes have been followed by an intensification of floods, increased bank cutting, and an increase in the silt burden of flood waters in the Chama River. Some of the once fertile irrigated farm lands on the river have become silt-sand wastes.

Interspersed with the timber types, a rather dense chaparral type occurs largely on high mountain slopes. The brush consists principally of scrub oak, New Mexican locust, and aspen, with an undercover of grasses and other herbs. This type affords a high degree of watershed protection. Fire is very injurious to it and the destructive grazing, also, has greatly impaired its protective value.

Above the commercial spruce stands is the subalpine forest type, consisting of scattered patches of spruce and fir interspersed with grassland or brush areas. Few of these small patches of timber have been depleted. With their rather dense growth, large quantity of litter, and herbaceous and shrubby vegetation they control erosion and reduce surface run-off from snow and rain to an almost negligible quantity. The grasslands intermixed with these timber clumps furnish a very effective watershed cover unless depleted. Being naturally good forage, before the creation of the national forests they were subjected to severe overgrazing which thinned the grasses and often caused them to be replaced by a scant stand of weeds of far less value in controlling run-off and erosion. The rather deep soil common on grassland areas of the subalpine type has been rather severely eroded. This erosion has not yet been entirely controlled, although on most of the eroded areas a protective grass cover is being restored. The rapid run-off made possible in part by the system of gullies in this grassland type, and the eroded material carried by this run-off, have tended to cause continuance of active cutting of stream banks in timber areas below.

Of the 17,460,000 acres of forested land in the Rio Grande Basin, 14,168,000 acres has been classified as of major influence and 3,292,000 acres as of moderate influence in watershed protection. (See figs. 6 and 12.)

## LAND MANAGEMENT AS AFFECTING WATERSHED PROTECTION

Measures necessary to correct unsatisfactory erosion and run-off conditions at the source, on the slopes of the watershed, include eliminating destructive grazing and timber cutting, controlling fires,

aiding restoration of suitable vegetative cover, and modifying highway construction to obviate unnecessary acceleration of run-off.

At the time when most of the national forests in the upper Rio Grande Basin were created, about 27 years ago, overgrazing and depletion of forage cover were widespread in this drainage. Destructive lumbering and fires were common, also. Although excessive erosion is not yet checked on all the 5,364,000 acres of forest lands within the national forests of the basin the vegetative stand is now declining on few national-forest areas. Not only has the regulation of grazing benefited the livestock industry by providing more adequate range feed on the greater part of the national forests, but the improvement in range conditions has materially reduced the rapidity of run-off and soil washing. Timber is now cut under regulation and fires are controlled with little loss of forest values.

On the 2,820,000 acres of forested public domain land in the upper Rio Grande Basin, the use of which is practically unregulated, cutting of trees is locally excessive, fires are often allowed to burn without efforts at control, and most of the range is still deteriorating. The public domain is often intermingled as alternate sections with railroad grant lands or with State lands or private holdings. Under such conditions it hampers attempts to control range use on these lands. It should be placed under public administration.

State lands within the national-forest boundaries are ordinarily managed under cooperative agreements which assure reasonably good fire protection and timber-sale administration. Those outside national forests are seldom so well managed. State forested lands are usually leased for grazing without any provision for maintaining the range resource or for protecting watershed values.

Cut-over lands in this basin which once had stands of saw timber offer little promise of profitable timber production in private ownership at present. Timber growth is slow, timber values are not high, and current returns from grazing or other uses will hardly pay taxes, fire-protection costs, and interest on the investment. However, uncut saw timber now privately owned will doubtless remain in private ownership until cut. In 1931 more than half the private forest land bearing stands of saw timber was protected from fire through cooperative agreements between the owners and the State or Federal Governments.

While range management adequate for satisfactory watershed protection prevails on some private forested lands, on far too many such holdings the range is in as bad a condition as on the public domain. The large values in the agricultural valleys that are endangered by these erosion conditions would warrant drastic remedial action. Private lands totaling about 5,000,000 acres showing excessive deterioration of cover on steep slopes or on soils that are readily eroded should be acquired by the public within the near future, and either totally protected from grazing or subjected only to drastically restricted grazing until a suitable plant cover has been restored.

In the vicinity of the numerous Mexican and Indian settlements both within and outside the national forests, where agriculture has been practiced for many years, erosion and floods have in many instances decreased or eliminated irrigation farming. This has resulted in increasing the intensity of other land uses such as grazing over a large area around each settlement. To permit the last vestige

of plant cover to be eliminated, as is occurring about many of these settlements, means lasting destruction of watershed-protection values. How to correct this situation without destroying an already unstable economic structure is a problem demanding most intensive study and one the importance of which cannot be overemphasized.

The danger of serious erosion resulting from construction of forest roads on soils that are naturally unstable and that are readily eroded has seldom been given adequate consideration within this basin. In many instances abnormal run-off, accumulating in roads or in drainage ditches built to protect roads, has cut veritable canyons in slopes and valleys. In very few such instances has the erosion been checked. Drainage methods that will turn water from mountain roads before it has accumulated to destructive proportions, and methods of developing a cover on bare cuts and fills, deserve much greater attention.

Because channel cutting is progressing at such a rapid rate, extensive engineering works are justified as a supplement to restoration of vegetation on slopes. The cost of engineering works adequate to control the erosion would be considerable.

Definite effort should be made promptly to control erosion and rapid run-off from slopes by restoring tree growth, understory vegetation, and litter. Intensive research is justified to determine just what forest cover is most effective for each soil and forest type and what use should be permitted. Where tree growth is necessary and where devastation has reached such a point that tree growth will not come back maturally, planting is recommended where it appears practicable. This would involve about 50,000 acres. Where the herbaceous vegetation has been so destroyed under open tree stands or in openings in the forest that its restoration will be slow, artificial reseeding should be resorted to as satisfactory methods are developed. Approximately 50,000 acres would appear to justify such reseeding immediately.

## GREAT BASIN

Adequate recognition has not been given to the need for watershed protection on forest lands of the Great Basin, which consists essentially of the eastward drainages of the Sierra Nevada of California, a portion of southern Oregon, most of Nevada, the western part of Utah, and small parts of southeastern Idaho and southwestern Wyoming (fig. 13). In this basin, drainage is all to the interior and, in the main, timber values are low. Here the watershed-protective function of forest lands derives its significance principally from the extreme demand for water for irrigation agriculture and for urban use, the scantiness of the water supply available, the danger of destructive silt-laden floods or even mud-rock flows from local drainage areas, and the necessity of protecting the soil against abnormal erosion and of restoring soil productivity on certain mountain lands.

### DEMAND FOR WATER, AND RELATION OF FORESTS TO WATER SUPPLIES

Irrigation agriculture and its related industries are the basic permanent industries of the Great Basin, although less than 2 percent of the area is irrigated. Irrigation is the main support of most of the communities. It is essential to such leading local industries as sugar man-

ufacturing, canning, dairying, and poultry raising, and plays a very important part in the sheep, beef-cattle, and meat-packing industries.

The great demand for water is well illustrated by conditions on the Sevier River. All the water in the channel is diverted several times for irrigation, 7 or 8 dams being used for this purpose and in part to form storage reservoirs. The return seepage from the agricultural lands below each dam supplies water for the next reservoir. In years of


FIGURE 13.—Great Basin.

normal or greater precipitation all the reservoirs fill at least above the point of dangerous water shortage. In years of sparse precipitation, however, 2 or 3 of which usually occur in every decade, the lower reservoirs and some of the upper ones fail to receive enough water for more than 1 or 2 irrigations and occasionally the lowest reservoir receives none.

Nearly all the water for irrigation comes as run-off from forest areas. These total some 20 million acres, only 14 percent of the whole basin area. They occur mainly above 5,000 feet elevation, on mountains and plateaus. Valleys or desert basins alternate with the

mountain chains. Another part of the water supply comes from large springs at lower elevations or from underground storage basins fed principally from forest-covered mountain slopes. The main irrigation developments depend upon large streams, but numerous small streams furnish the water necessary to irrigate a large number of widely scattered farms and ranches.

In the Sierra Nevada the principal coniferous timber types are the ponderosa pine at the lower elevations and a mixture of white fir, incense cedar, Douglas fir, and sugar pine at somewhat higher elevations. Still higher Jeffrey pine and western white pine come in, ultimately blending into the subalpine forest. In the eastern part of the basin the coniferous timber type is made up mainly of Douglas fir, alpine fir, and white fir, with some spruce. The aspen-fir-brush type is characterized chiefly by extensive aspen stands and by mixed stands of aspen, fir, and brush. It occurs principally in the eastern portion of the basin, on mountains and plateaus above elevations of 7,500 or 8,000 feet.

Both the coniferous and aspen-fir-brush types normally form a moderately dense cover of trees and subordinate vegetation, have a fair to good litter cover, and produce a rather deep layer of humus. Precipitation within these types is probably 20 inches or more in nearly all parts of the basin, and in some localities exceeds 40 inches. Much of this precipitation comes in the form of snow, which tends to accumulate, especially at the higher elevations. Rising temperatures in March, April, and May and occasional warm rains at that time cause rather rapid melting. The chief watershed-protective value of these types lies in maintaining a surface soil condition favorable to percolation of moisture from melting snow and rains, in retarding snow melt and surface run-off, and in checking erosion.

Water for domestic use, power, and other urban purposes, also, comes mainly from forest areas. Such important cities as Salt Lake City and Ogden, and more than 130 other communities having a population of 500 or more, obtain their supplies from these watersheds. Several rather large power developments have been installed on the main rivers to supply cities and large towns and in portions of Utah and Idaho included in this basin many towns have their own power plants on nearby streams.

### FLOODS

Of almost equal importance with adequate water supply is the control of local floods, which are destructive chiefly because of the excessive load of soil and rocks which they carry. Floods of greater or less seriousness have been reported from many areas within the Great Basin in the last 30 to 50 years, especially following destruction of cover on the watersheds through the excessive grazing which came with extended white settlement and through fires and heavy timber cutting. Some of the most destructive floods have occurred in the last 10 years in the thickly populated area near Salt Lake.

Studies made by Prof. Reed W. Bailey, [73] of the Utah Agricultural College, in cooperation with the Intermountain Forest and Range Experiment Station and the Utah State Land Board, have shown that the 75-foot or deeper channel cutting and the enormous amounts

[73] Bailey, Reed W., statement in hearings before the House Committee on the Public Lands on H.R. 11816, 72d Cong., 1st sess. 1932.

of debris deposited by these recent floods were far in excess of any earlier flood action in that locality since Lake Bonneville ceased to exist some 30,000 or more years ago.

In 1923, for example, disastrous floods occurred at Farmington and Willard, Utah. Mountain sides were gullied, farm property in the valley was destroyed, and six people were killed in Farmington Canyon. The damage to town and farm property at Willard was between $75,000 and $85,000. Again, in 1930 and 1932 increasing numbers of areas in Davis, Salt Lake, and Utah Counties were flooded. Newspapers estimated the damage at more than $1,000,000. The Red Cross report on floods in these counties in 1930 states that 179,200 acres of high-priced truck and orchard land was flooded and 295 acres of such land rendered completely useless, that 134 families were left homeless. It cost Utah about $100,000 to clear the State highway.

By careful examination after the floods of 1930 the Governor's special flood commission established[73a] that the silt-laden flood water had collected chiefly on small areas of private land at the heads of the drainages where the vegetative cover had been seriously depleted or destroyed by overgrazing, by fire, and to some extent by timber cutting. This was determined by observing where gullies 10 to 20 feet deep led into the main channels. From these large gullies smaller ones radiated out into many tiny channels on almost barren spots where the surface soil had been entirely stripped away through sheet erosion. The steep slopes, at intermediate elevations, that make up the greater part of the mountain face bear a dense brush or forest cover. No gullies originated on these slopes, where the plant cover and thick litter restrained the surface flow sufficiently to permit effective penetration of water into the mellow humus-filled surface soil and prevent undue soil or water losses. The results of examinations made in 1931 and 1932, by representatives of the Utah Agricultural Experiment Station, the Utah State Land Board, and the Intermountain Forest and Range Experiment Station, of more than 15 recently flooded areas in Utah and the watersheds from which the floods came show a similar relation of cover depletion on small critical areas to rapid run-off and floods.

Paul and Baker,[74] reporting on the 1923 floods of northern Utah, attributed the floods to destruction of cover at the heads of stream courses.

That floods in the Great Basin can at least be alleviated is clearly indicated by Forest Service studies on the Manti National Forest, in central Utah. The forest and brush covered slopes and subalpine grassland openings of the Manti Canyon watershed, for example, had been badly overgrazed by cattle and sheep as early as 1890. Reynolds [75] pointed out that—

> between 1888 and 1905, the Wasatch Range, from Thistle to Salina, was a vast dust bed, grazed, trampled, and burned to the utmost.

No flood of consequence occurred in Manti Canyon before 1888, but the canyon discharged serious floods in that year and in 1889, 1893,

---

[73a] "Torrential Floods in Northern Utah, 1930." Report of Special Flood Commission. Utah Agr. Expt. Sta. Circ. 92. 1931.

[74] Paul, J. H., and Baker, F. S., "The Floods of 1923 in Northern Utah." Univ. of Utah Bul. v. 15, no. 3, 1925.

[75] Reynolds, Robert V. R., "Grazing and Floods: A study of conditions in the Manti National Forest, Utah." U.S.Dept.Agr.For.Serv.Bul. 91, 1911.

1896, 1901, and 1902. Beginning in 1904 livestock were excluded from the canyon except for drift (the national forest was established in 1903). By 1909 the vegetation had materially improved. A heavy storm in August 1909 that resulted in floods from the still depleted Ephraim and Six Mile Canyons, on either side of Manti Canyon, caused little injury in Manti Canyon. On September 18 and 19, 1910, a 1.59-inch rainfall following one of 1.16-inch on September 16 in the grazed Ephraim Canyon resulted in a heavy flood. A 1.18-inch rainfall on September 18 and 19 following a 1.51-inch rainfall on September 16 in the protected Manti Canyon produced no flood. Since then destructive floods have been unknown in Manti Canyon. In recent years there has been a considerable improvement in the vegetative cover in Ephraim Canyon, and no floods of consequence have occurred.

That the restoration of herbaceous cover in large openings in the subalpine timber type contributes to the control of surface run-off and erosion from summer storms is shown by studies of the Intermountain Forest and Range Experiment Station [76] on two watershed areas of about 10 acres each in the head of Ephraim Canyon, Utah. Alpine fir, spruce, and brush occupy completely a few square rods of each area; otherwise, the cover consists of herbaceous vegetation only. In 1915, when the studies began, one area (B) was in reasonably good condition, about 40 percent of its soil surface being covered largely with perennial grasses and weeds. This cover was maintained during the study period, through careful grazing management. The thin vegetative stand, mainly of annuals, that was present on the other area (A) in 1915 occupied only about 16 percent of the soil surface. After being maintained in about that condition for 6 years the cover on this area was improved, through protection from grazing and through artificial reseeding, until about 40 per cent of the soil surface was covered, chiefly with perennial grasses and weeds.

By comparing the quantities of surface run-off and of sediment removed from the two areas during the 6-year periods 1915–20 and 1924–29, as a ratio of results on A divided by those on B, it was found that the increase in vegetative cover on area A had caused a reduction of 64 percent in surface run-off from summer rains and a reduction of 54 percent in soil material removed in erosion by summer storms. An even greater percentage reduction occurred in the difference between areas A and B in the two periods in respect to the surface run-off and sediment removed per inch of summer rainfall. The actual quantity of soil removed from area A was 133.8 cubic feet per year in the 1915–20 period and only 19.2 cubic feet per year for the 1924–29 period. This decrease is not precisely representative of the results of the increase in vegetative cover since the rainfall was lower in the latter period than in the former. Since, in the three years of record, summer storms carried off 85 percent of all the soil washed from area A annually during the period when the cover was depleted, and since summer storms are largely responsible for the destructive floods in this locality, these reductions in summer run-off and quantity of sediment carried by summer run-off indicate a definite influence of plant cover in reducing danger of destructive floods from rains on such mountain watersheds.

---

[76] Forsling, C. L., "A Study of the Influence of Herbaceous Plant Cover on Surface Run-off and Soil Erosion in Relation to Grazing on the Wasatch Plateau in Utah." U.S. Dept. Agr. Tech. Bul. 220, 1931.

## EROSION

As these flood situations indicate, in the Great Basin erosion of mountain and foothill slopes is intimately related to flood destructiveness. Some floods are so heavily charged with erosion debris that they become mud-rock flows. Doubtless the most serious phase of this erosion, however, is soil wastage from slopes. Close observation of soil conditions on the Wasatch Plateau in central Utah indicates that in large areas of open grassland in the forest, 6 inches or more of the fertile topsoil has been lost through sheet erosion. Observations by the Forest Service show that in the juniper-sagebrush type along the edges of the Toyabe National Forest, Nev., on private land, on the public domain, and to some extent on national-forest land, considerable areas are cut with shoestring or larger gullies, accompanied by sheet erosion. In Reese River Valley, also, there are gullies 2 or 3 feet to 8 or 10 feet deep in this type. Another area a few miles north of Elko shows considerable surface erosion and some gully erosion. On most of the forest area in the Great Basin erosion has not gone so far but that it can undoubtedly be checked by restoring the vegetative cover.

While abnormal erosion has been severe in all forest types in the Great Basin, preliminary surveys by the Forest Service show that it is most serious in the pinon-juniper type, which occupies two thirds or more of the basin. This type is largely characterized by orchard-like stands of pinon and juniper, scattered oak and other brush, and herbaceous growth. The pinon-juniper type occupies the lower, drier foothills and mountains, where the annual rainfall ordinarily totals only 12 to 16 inches, part of which may come in occasional semitorrential rains. At best the vegetation is scant and little litter accumulates. On large parts of the area, particularly in the public domain, even this scant stand has been reduced one half or more. Sheet and gully erosion occurs almost throughout the pinon-juniper type, although within the national forests the vegetative cover in this type has shown on the whole a slow but steady improvement and the excessive loss of soil is being checked.

The loss of soil productivity through erosion is shown by studies of the Intermountain Forest and Range Experiment Station of soils from openings of the subalpine timber type in Ephraim Canyon. The growth of many-flowered bromegrass and of wheatgrass was more than twice as great and that of peas more than eight times as great on noneroded as on eroded soils. Furthermore, eroded soils used 38, 23, and 80 percent more water for each pound of growth in bromegrass, wheatgrass, and peas, respectively, than did the noneroded soils.

## WATERSHED-PROTECTION REQUIREMENTS

The 19½ million acres of forested land within the Great Basin has been classified according to watershed-protection influence as approximately 5½ million acres of major influence, 12 million acres of moderate influence, and 2 million acres of slight influence. (See fig. 13.) Those lands classified as of major influence are chiefly mountain forested areas, the water from which is in great demand or on which, if their cover becomes depleted, destructive floods may originate, and foothill or low mountain areas, chiefly woodland, having readily erosible soils, the erosion of which might seriously endanger irrigation

or other works or add to flood destructiveness. Those areas classified as having a moderate watershed-protection influence are chiefly woodland areas from which little water normally is delivered and the erosion of which would not seriously damage lands other than the forested areas themselves. A rather large area in northeastern California supporting ponderosa pine, lodgepole pine, and woodland species has been classed as having a slight influence on watershed-protection values. Most of the area is level or of rolling topography. Its soils, derived from volcanic rocks or dust, absorb precipitation readily, and run-off and erosion are seldom serious.

By far the most important requirement for overcoming the unsatisfactory watershed-protection conditions in the Great Basin is control of grazing. Timber cutting and fires also must be controlled. On the 6,670,000 acres of forested lands within the national forests, where grazing and timber cutting are regulated and fires are held to small acreages, forest cover conditions are, in general, improving, and erosion and extremely rapid run-off are being checked.

There is nearly 9 million acres of public domain in the woodland, mountain brush, and timber types within the basin. Most of this is not now producing anywhere near the quantity of forage or protecting vegetative cover that it could produce were it placed under public administration. Conditions on private and State lands are little, if any, better. Many areas in the woodland and lower-brush types have been so badly overgrazed and burned that hardly anything is now growing on them except downy bromegrass, an annual of very low value from either a grazing or a watershed-protection standpoint. On some areas of readily erosible soils where the herbaceous vegetation has been practically destroyed it may be necessary to eliminate grazing for a time in order to restore a suitable protective covering, unless it is possible to find plants that can be established artificially on these areas. On by far the greater percentage of the basin area, however, adequate regulation of grazing will doubtless restore a satisfactory watershed-protection cover.

The State, county, or Federal Government should acquire about 1,800,000 acres of major-influence forest land, especially the critically denuded areas at the heads of canyons, now in private ownership, from which destructive floods have come. On these areas, in order to restore the forest or herbaceous cover, it will be necessary to correct present overgrazing and to seed or plant erosion-control plants. Dams in the larger gullies and terraces seeded to grasses or other plants on the steeper denuded slopes will aid in attaining control of erosion in a reasonable period. Some 50,000 acres in this basin should be planted to trees and an additional 200,000 acres reseeded to grasses or other herbaceous erosion-control plants.

## COLUMBIA RIVER BASIN

The Columbia River Basin (which as here considered includes only lands east of the Cascade Divide) drains parts of Washington, Oregon, Idaho, Montana, Wyoming, Utah, and Nevada, and also a part of Canada, as is shown by figure 14. It is a region of valuable forest growth, heavy snows, rapid spring run-off, large and valuable irrigation developments, extensive power possibilities, great demands for domestic water supplies, and large areas of easily erosible soils.

FOREST TYPES AND THEIR WATERSHED-PROTECTION VALUES

Of the 204,873 square miles in the basin 92,226 square miles (approximately 59,025,000 acres), or 45 percent, is forest land, located principally in the rougher mountain country. This forest land supports some of the most valuable timber in the West.

Near the point where the Columbia River passes through the Cascade Range the Pacific Coast Douglas fir type occurs, forming a dense stand of large trees with heavy undergrowth and litter. Where uncut and unburned it serves unusually well in controlling run-off of the heavy precipitation which occurs in that part of the drainage, often totaling 80 inches a year. Chinook winds in winter sometimes

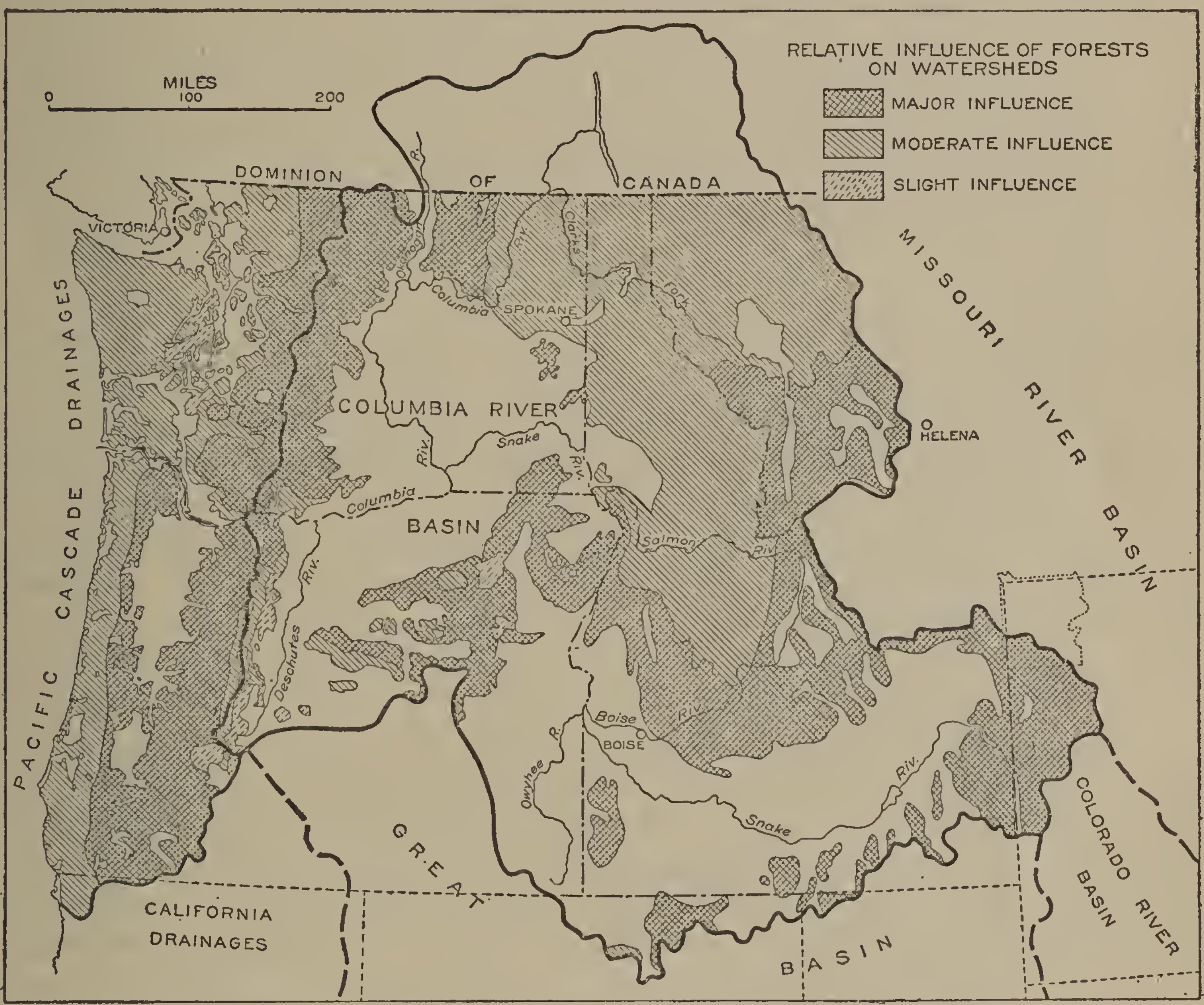


FIGURE 14.—Columbia River Basin and Pacific Cascade drainages.

cause such rapid melting of snow as to bring about floods of short duration. After fires the land is likely to reclothe quickly with a new growth of timber reproduction or of shrubs and herbaceous vegetation that is effective in preventing erosion and, at least moderately, in slowing down run-off. The Douglas fir areas have been classified as of major watershed-protection influence.

On areas of lower precipitation throughout the basin, at the lower fringe of the timber, the main tree cover is scattered ponderosa pine or juniper. The trees ordinarily do not form a closed canopy. Litter is scant. Here precipitation usually averages about 15 to 25 inches a year, with a dry summer period. Run-off from these forests is not particularly large or rapid except in occasional instances when snows melt rapidly or semitorrential rains fall. In these open forest stands the principal erosion-control influence is the undergrowth of herbs and shrubs. On large areas the perennial herbaceous vegetation has

been seriously depleted. Studies by the Forest Service in southern Idaho have shown that in the main these open timber stands, under satisfactory management and with a good understory of a herbaceous plants, are highly effective in controlling abnormal erosion that would otherwise become serious. Where such conditions prevail, these forests have been classified as of major watershed-protection influence. In the volcanic pumice soils, especially in central Oregon and part of eastern Washington, absorption of rain and melting snow is normally so rapid, and the danger of abnormal erosion so slight, that where these forests occur on such soils their watershed-protection influence has been classified as moderate or slight.

At intermediate elevations the forest is more dense, made up chiefly of ponderosa pine, often with an intermixture of larch or fir. The western white-pine type occurs as an unusually dense forest with a heavy litter on the better soils, especially of northern Idaho. Usually above these types but also intermixed with them in places are extensive stands of lodgepole pine. Mixed with these several types and sometimes occurring as an individual type is Douglas fir. In these types precipitation is somewhat higher than in the lower fringe types. It ranges from as low as 20 inches in the ponderosa pine type at the lower elevations to 50 inches or more at higher elevations. Summers are normally dry; much of the precipitation comes in the form of snow, which accumulates to depths of 5 or 10 feet or more. The melting of this snow causes a high spring run-off and sustains reasonably well a low summer stream flow from underground seepage. An adequate forest litter prevails which together with the timber and understory vegetation ordinarily controls erosion and regulates stream flow rather effectively.

In northern Idaho and northeastern Washington these dense forests have been classed as of moderate watershed-protective influence. In this section water yield is normally high, the demand for water is only moderate, and erosion is seldom serious, although the loess soils characteristic of the region are eroded readily if exposed. After destruction of the cover by fire a plate moss forms on the soil and holds it in place until brush, herbs, and timber reproduction reclothe the soil completely. Erosion of course can become serious if this reclothing is hindered by overgrazing.

Types in which the timber and other growth is dense have a very high watershed-protection value on the easily eroded granitic, clay, or clay-loam soils and where delivery of maximum quantities of usable water is important, as in southern Idaho. On the pumice soils of Oregon and Washington these dense forests exert a slight to moderate moisture-conserving influence through delaying snow melt and improving and protecting the soil with their litter.

In the upper reaches of Clark Fork River, in western Montana, forest types commonly in more open stands are of major watershed-protective influence. The demand for water and the need of regular stream flow are great. Erosion may become serious if fire, grazing, or some other agency thins the cover, since revegetation tends to take more time than in the more humid area on the lower reaches where the forest is classed as of moderate watershed-protection value.

Excessive run-off and erosion occur on areas around Butte and Anaconda, Mont., that have been rendered practically barren by smelter fumes. The fumes have killed tree growth over an extensive

area, but on much of the affected area sufficient grass remains to retard abnormal erosion.

The subalpine forest, usually scattered growth or patchy stands of alpine fir and white-bark pine with intermingled grass or brush lands, occurs at the higher elevations, extending to timber line where winter snow depth often exceeds 10 feet. The patches of tree growth, together with good stands of herbaceous and shrubby vegetation in the openings, serve very well for erosion control and bring about a rather satisfactory delivery of the heavy snow blanket. When the herbaceous cover is broken the value of the type for erosion control ordinarily is impaired.

Brush fields, often the result of fires, are intermixed with areas of dense timber. The dense growth of brush, the understory of grasses and other herbs, and the litter formed within the brush clumps control erosion with unusual effectiveness unless the cover is depleted. Forest Service studies in southern Idaho have shown that on extremely steep brush slopes the dense vegetation and the loose soil maintained under the brush cover facilitates rapid absorption of moisture, and erosion is negligible.

### WATER-SUPPLY PROBLEMS

How to obtain adequate water for irrigation on the Columbia River drainage without excessive cost for storage is a great problem, which becomes more intense when rainfall is subnormal for several years, as has recently been the case on much of the area. The large quantity and high values of the irrigated land, as well as the high average annual returns from the land, make irrigation agriculture a dominant industry. According to the 1930 census irrigated land in the basin totals 3,389,000 acres and represents an investment in lands, buildings, irrigation enterprises, and implements of several hundred million dollars.

Many large irrigation projects are found in the basin, including the Twin Falls and Boise projects of Idaho and such important apple-producing areas as the Yakima and Wenatchee of Washington and the Hood River of Oregon. Of outstanding importance is the projected Columbia Basin project of Washington, which involves irrigation of some 1,200,000 acres. Many other areas are capable of irrigation development; in southern Idaho, for example, there is more than 2,600,000 acres of irrigable land.

Water power, also, is of great importance in the Columbia River Basin. On the Snake River and its tributaries of southern Idaho, for example, 166,000 horsepower has already been developed. The Lake Chelan development alone has a present capacity of 125,000 horsepower. Smaller plants are in operation on many rivers, and the undeveloped possibilities in the basin run into several million horsepower. The domestic water supplies of numerous cities and towns, also, originate chiefly on forested watersheds of the basin.

The influence of forest cover in regulating stream flow in the Columbia River Basin is indicated by a preliminary Forest Service study in the Clearwater River drainage in northern Idaho, previously discussed. The burning of some 535,424 acres, or 17.7 percent, of the watershed in 1919 caused the following changes in stream flow in the 5 subsequent years as compared with the 5 years prior to the fire: (1) An average advance of 14 days in the date of peak flow; (2) 9.5 percent

greater average flow on peak days, and nearly 36 percent greater flow in May; (3) an increase in the flow during the period April to June, inclusive, from 66 percent of the total annual flow to 73 percent; (4) a decrease in the flow during the period July to September, inclusive, from 13 percent of the yearly flow to only 9 percent; and (5) approximately 96.5 percent as much run-off from 88 percent as much precipitation. These changes are of great moment. April to June flow is, of course, chiefly the result of surface run-off from melting snow, while July to September run-off results almost entirely from the slow drainage of ground water. The effect of the fires appeared to increase the spring flood flow, and to do this largely at the expense of ground storage of water that would have fed the streams later in the year, particularly during the summer period.

## EROSION

Of equal or greater importance with effective regulation of stream flow is control of erosion. A large part of the forested area of the Columbia River Basin is made up of coarse, readily erosible granitic soil. This soil is so loose that where plant cover is scarce or absent it is readily swept off in sheet erosion. Rapid run-off then forms gullies from a few inches to several feet deep. Loose soil on the edges of the gullies soon crumbles, and within a year or two after being formed many of the smaller gullies have so smoothed over as to be almost unnoticeable. Such abnormal erosion is taking place over extensive areas.

How serious such erosion is on this granitic soil is shown by a Forest Service survey of a part of the Boise River watershed in Idaho. Approximately 62 percent of an area of nearly 350,000 acres had suffered distinct sheet erosion and 10 of this 62 percent was also cut by gullies of a type not readily obliterated by creeping soil. Depletion of vegetation from past overgrazing and trampling by livestock of soils inadequately protected by vegetation are important causes of the erosion. Of the 190,991 acres in the grazed timbered area, sheet erosion had taken place on 64 percent, and on 8 of this 64 percent gully erosion also had taken place. Of nontimbered grazed areas more than 78 percent had suffered sheet erosion and 15 percent included in this had suffered gully erosion. Of the 52,817 acres of timber and brush areas where the cover was too dense or the slope too steep to permit grazing only 16 percent showed sheet erosion and but 2 of this 16 percent showed gully erosion.

In many places crowns of old grass plants are found elevated 4 to 8 inches above the surrounding surface, from which erosion has removed all fine dark soil, exposing a raw, inert stratum of unconsolidated gravelly sand that offers no real resistance to water erosion. On those areas protected by a dense cover of timber, wheatgrass, and yarrow, or of mountain brush a mellow black soil 6 to 18 inches deep still remains and soil loss through normal erosion is probably offset by soil formation.

Studies by the Intermountain Forest and Range Experiment Station in this locality showed that noneroded soils contain from 6 to 19 percent organic matter as compared with ½ to 4 percent in the raw eroded soils. The average water-holding capacity of the soils of greater humus content was 81 percent, as compared with only 44 per-

cent for the eroded soils lacking in humus. On the latter soils there is no measurable depth of litter, whereas there is 1 to 3 inches of litter on lightly grazed noneroded soils of nontimbered areas and 1 to 6 inches on the soils of densely timbered areas.

Some rather large areas of private forest within the Columbia River basin have been heavily cut and burned, and this has caused material thinning of the timber stand and some erosion; the principal cause of erosion, however, has been the decline of the herbaceous undergrowth of the forest, largely from overgrazing but in part from fires. Bunch grasses, which in good stands effectively control erosion and build soil, have, over large areas, been almost replaced by downy brome and other inferior annuals or perennials. This replacement is especially marked on the several million acres of forest land in the public domain. Forage production on the forested public-domain areas and on intermingled private land has been found by Forest Service observers to have been reduced in many instances by from 50 to 80 percent. Such conditions are adversely affecting the livestock industry as well as the watershed-protection values of the forest.

## FLOODS

Where only scant cover is present on the watersheds to interrupt run-off, the combination of semitorrential rains, rapid snow melt, and ready formation of gullies causes local floods on many of the smaller tributaries. These local floods sometimes do considerable damage, destroying improvements and depositing mudrock flows at the mouths of the drainages, sometimes destroying good agricultural land.

A cloudburst in 1932 on Loon Creek, on the Challis National Forest in Idaho, for example, caused heavy run-off to originate on a 1931 burn, resulting in a deposit of sand and debris in tributaries of the creek so heavy as to destroy fishing in parts of this stream for at least several years. A similar rain in 1932, on a 1931 burn on the watersheds of Richardson and Mann Creeks, on the Idaho National Forest, caused a heavy flood that cut deep gullies, gutted stream channels to bedrock, and swept debris down these canyons into the Salmon River. The mud flow at the mouth of Mann Creek dammed the Salmon River to a depth of 20 to 25 feet and for a length of 450 feet, causing the formation of new temporary rapids.

High water can be expected practically every spring in nearly all important tributaries of the Columbia River as a result of the melting of the large accumulations of snow in the mountains. This high water in the main streams seldom assumes the proportions of destructive floods, although usually it causes minor damage along the stream courses. It does, however, move a considerable quantity of silt which has collected in small tributaries down to the main river channels. By 1930, 15 years after the construction of the Arrowrock Dam of the Boise project, silting was estimated to have reduced the storage capacity of the reservoir by 7,000 to 8,000 acre-feet. This amount of storage space represents more than $100,000 of the original cost of the dam. Officials of the water-users' organization estimated that by 1930 the sand deposit at the power dam had reduced its capacity by 25 percent, and considerable silting of canals and other irrigation works has caused additional expense.

Another reason for preventing silting of the Columbia River is the use of the river for navigation. The value of shipping and of rafts of logs and piling moved on the Columbia River annually from 1926 to 1930 amounted to about $383,000,000.

## PRESENT WATERSHED CONDITIONS ON FEDERAL AND OTHER LANDS

In the Columbia River Basin fire is by far the most damaging influence on the watershed-protection values of the forest. Summers are normally rainless, and with relative humidities often below 10 percent. Under such conditions the heavy accumulation of litter, the drying of herbaceous vegetation, and the density of the timber growth combine to make a serious fire hazard. Insect killing of such species as lodgepole pine over extensive areas has added to the depth of the litter and to the difficulty of controlling fires once they are well started.

Fires burn hundreds of thousands of acres in the Columbia River Basin nearly every year. In dry years the fire situation becomes almost catastrophic. Very drastic and energetic measures have been taken by the Forest Service to overcome the extreme natural fire hazard and reduce the national-forest area burned yearly to a point at which serious impairment of timber growth or watershed values will not be involved. In northern Idaho, for example, for watershed areas where the watershed-protection values of the forest are classed as moderate the best information available places the permissible burn at about 0.7 percent per year, or 7 percent in 10 years. Where the watershed-protection values of the forest are rated as high, the limit of annual burn should not be greater than one half of 1 percent. Even on national-forest lands, unfortunately, the average area burned during the 10-year period 1921–30 exceeded the allowable percentage, particularly in the valuable commercial timber types such as the larch-fir, western white pine, and cedar-hemlock. On the Clark Fork River drainage 24 percent of the western white pine area was burned over. If such losses continue, profitable timber growing in these valuable types will become impossible. For timber production, allowable burns in these types would normally be less than those indicated above for watershed protection. Accordingly if fires can be so far controlled as to permit profitable timber production, it is reasonable to assume, watershed-protection requirements will be met.

On private lands outside the national forests fire protection is even less satisfactory. It is probable that few private owners will attempt to carry their cut-over land until it is ready for another cut, for much of this land has already been devastated by excessive cutting and fires. As more and more private lands are cut over the incentive for fire protection becomes less. Thus it is to be expected that damage to watershed values by fire on private lands will increase unless more adequate fire protection is provided.

Large areas of cut-over land are reverting to public ownership for nonpayment of taxes. On many such areas, fire control is far from what it should be. Timber cutting is often severe, and where fire follows cutting devastation is widespread, materially influencing the watershed values. On some rather large areas still in the unreserved public domain, reburns of timberlands cut over in the early days are greatly adding to deforestation.

Present logging methods ordinarily do not seriously injure watershed values except where logging is followed by fire. On national-forest lands, cutting usually is more or less selective and leaves an understory of young trees and underbrush. On private land, also, cutting is seldom so severe at the present time as to have serious effects on watershed values except on some western white-pine areas. On certain large areas, however, for example in Idaho, the timber has been practically clear cut and burns to clear the slash have seriously delayed restocking to timber, thus materially reducing protection values.

Overgrazing is or has been an important factor in unsatisfactory watershed conservation throughout the basin. On some areas, especially in northern Idaho and western Montana, demand for grazing is so light that watershed values are not greatly endangered by grazing use. On many forest areas in southern Idaho, eastern Oregon, and central Washington, however, because of easily erosible soils, steep slopes, open tree cover, and semitorrential rains, overgrazing has created a critical erosion problem. On large private holdings grazing is usually leased without restriction on use. Because of overgrazing in the past and even at present, the vegetative cover on many private lands and on the public domain is so seriously depleted that it does not effectively protect the soil against erosion. Heavy grazing together with the trampling of livestock, especially on loose, granitic soil, tends to destroy the vegetation and litter that normally would keep the top layer of soil mellow and open.

## REQUIREMENTS FOR WATERSHED PROTECTION

On the 34,755,000 acres of forest land within the national forests in the Columbia River Basin, watershed conditions are in the main rather good. Fire protection needs strengthening. Cutting is ordinarily not detrimental. Although forage conditions are improving or being maintained on most range areas, overgrazing has not been entirely corrected and some special adjustments on critical areas may yet have to be made. In general, conditions are rather good also on the 2,225,000 acres of forest land in Indian reservations.

Practically all the forest area on the public domain, amounting to about 1,776,000 acres, could justifiably be added immediately to the national forests for the purpose of watershed protection. Grazing regulation on this area should permanently benefit the livestock industry, as well as assuring more adequate protection to watershed values. Greater effort to control fire is needed. In addition, timber cutting should be regulated more strictly.

Since few counties can afford adequate forest fire protection, it seems logical that the States or the Federal Government should acquire a considerable part of the private lands that are reverting to public ownership for nonpayment of taxes, in order that the watershed and other values of these lands may be adequately safeguarded. Available data point to the need for public acquisition of about 12,400,000 acres of forested watershed lands in this basin.

On badly depleted areas efforts should be made to restore a cover that would be more profitable and that would protect the soil and water flow more effectively. The area on which forest planting will be necessary for watershed protection is roughly 150,000 acres.

Many of the burns in the western white pine type, for example, should be planted with trees. About 200,000 acres of openings in the forest where the vegetation is depleted, but where moisture conditions are favorable, should be reseeded to herbaceous erosion control plants. If practical methods for artificial reseeding of the drier low-elevation forest ranges to forage plants can be developed, many of the areas, now supporting a thin cover of annual plants, should be restored to a perennial type of vegetation more typical of what they formerly produced.

Thorough research is justified to determine just what cover is most satisfactory for the different exposures, soils, and other conditions, how to restore and maintain such a cover, and what utilization if any can be permitted under various watershed conditions.

## PACIFIC CASCADE DRAINAGES

The region west of the Cascade Range of Oregon and Washington (see fig. 14) is one of heavy precipitation, deep snows, and steep and rugged topography, all conducive to heavy and rapid run-off. Over most of the drainages the forest growth is dense, as a result of heavy precipitation, fertile soils, and a long growing season. The forests are predominantly Douglas fir, with western hemlock and silver fir also prominent. At the higher elevations occur mountain hemlock and alpine fir. A heavy undergrowth, principally of brush and ferns, combines with the tree growth and thick litter to form a protective cover for the slopes, which is unusually effective in conserving moisture and preventing erosion. The forest reaches elevations of 4,500 to 6,000 feet in the northern Cascades and 7,000 feet or more in the southern. At the upper elevations the forest is mainly open and is often difficult of access. Above the forest are rugged mountain ridges and numerous peaks, several with glacial fields. Of the total area of 49,450 square miles in these Pacific Cascade drainages 41,386 square miles (about 26,487,000 acres) is forested land or potential forest land now bearing a brush cover. Of this area approximately 15,564,000 acres, principally the steep slopes of the Cascade Mountains, has been classified as having a major watershed-protection influence, 9,509,000 acres, largely bordering the Pacific coast, as having a moderate influence, and 1,414,000 acres, chiefly on islands in Puget Sound, as having only slight to no influence.

Because of the extremely heavy precipitation, averaging from 50 to 75 inches and in some places totaling as much as 125 inches a year, the heavy snowfall, which at the higher elevations totals 30 to 50 feet, and the occurrence in winter of Chinook winds accompanied by warm rains, floods are inevitable. Stream channels have, in the main, adapted themselves to take care of large amounts of water. Occasionally, however, floods do considerable damage to high-value land and improvements.

Owing to the abundance of water and the great fall in streams, these drainages contain the greatest concentration of waterpower resources in the United States. About 625,000 horsepower has already been developed, at a cost of more than $65,000,000, and more than 4,500,000 horsepower remains to be developed.

A very large population draws upon the water supplies of these drainages for municipal use. Seattle, Tacoma, Portland, and prac-

tically all the smaller towns and cities obtain their water from forested watersheds. Most of these municipal watersheds are within national forests and have been set aside as special reserves on which other uses are restricted or entirely eliminated. The larger cities have developed water storage for dry periods. The pure, clear water from the heavily forested slopes is ideal for municipal use and for long life of storage reservoirs.

Within the upper Willamette, the Rogue, and other river drainages of southwestern Oregon, irrigation has made it possible to produce high-value crops such as fruits and vegetables in the rather dry interior valleys. Approximately 80,000 acres of otherwise low-value land has been placed under irrigation, and as a result a considerable number of prosperous communities and cities have been developed.

Without forest cover or other protective vegetative growth the soil over the greater portion of these drainages would erode easily; where there is a heavy forest cover, however, indications of erosion are practically lacking. Logging operations cover some 200,000 acres in these drainages each year, but because of the heaviness of the timber growth the individual logging areas are relatively small. The destructive logging methods used in the Douglas fir type, including the burning of slash following cutting, expose the soil to sheet and gully erosion. Rank herbaceous vegetation and a brush cover of sprouts quickly reclothe the soil surface and check whatever erosion has started. It is but a few years until the rapidly growing timber reproduction which comes in thickly on the exposed mineral soil following the slash burn overtops the low-growing vegetation and true forest conditions are restored. If repeated fires take place, however, the timber cover is destroyed and forested areas are transformed into brush fields, which according to Forest Service observers are less capable of retarding snow melt and of regulating stream flow from the heavy precipitation.

On the upper slopes of the Cascade Range, particularly in the northern part of the range, avalanches occur commonly. Occasionally they have been exceedingly destructive of life and property. Many of them start above timber line, on steep slopes at the heads of canyons, and follow a definite course down the canyons. Such avalanches, known as "canyon slides", occurring almost yearly, keep a "slideway" thoroughly stripped of sizeable tree growth. This type of slide must be considered the inevitable consequence of very heavy snowfall on steep, nonforested slopes.

Another type of avalanche known as "slope slide" is characteristic of hillsides that were once forested but have been devastated by fires or logging. On such hillsides great areas of wet snow sometimes start to slide, as snow does on a steep roof, carrying with them all in their path. Slides of this type do not occur until the forest has been burned or cut, because the trees pin the snow blanket to the ground, so to speak, as nails hold the shingles to a roof. Keeping the steep slopes well forested will forestall the damage which such avalanches do to all in their path and to the valleys below.

The main slopes of the Cascades are within the boundaries of national forests. The national forests of the Pacific Cascade drainages include 8,588,000 acres of forested land in Federal ownership and large acreages of private forest holdings. Of the Federal lands within the national forests, the watershed-protective influence of approximately 5,188,000 acres is classified as major and that of about 3,400,000 acres

as moderate. The dry summers make tinder of dense vegetative growth, and although energetic efforts are made to protect these lands from fire extensive fires still occur. Fire-suppression efforts must be further strengthened if timber and watershed values are to be adequately safeguarded. Under proper regulation the timber, grazing, wild-life, and recreational values of these lands are used advantageously without impairing watershed values.

Private holdings compose more than half the forested area of the drainages. Of this private land, approximately 8,576,000 acres are classed as of major watershed-protective influence, 4,781,000 acres as of moderate influence, and 868,000 acres as of slight influence. The usual practice is to clear cut the timber and burn the slash. This practice is ordinarily followed by satisfactory vegetation of the area. Fire protection is far from adequate on a large part of these private lands, especially on the cut-over timberlands. Reburns are frequent. Valuable timber reproduction has been replaced by brush, a change that materially increases the fire hazard. Cutting of private timber is often followed by tax delinquency and abandonment, which intensify protection difficulties. The net result of such conditions is a poorer watershed protective cover.

The drainages west of the Cascade Divide include approximately 1,897,000 acres of public domain and revested Oregon and California Railroad grant lands. The watershed-protective influence of these lands is classified as follows: approximately 1,200,000 acres, major; 482,000 acres, moderate; and 215,000 acres, slight. Timber is sold from the revested lands classified as timberland, but no provision is made for their permanent forest productivity. These lands are given some fire protection. No provision has been made, however, for protecting their timber from insects or disease, and bark beetles have killed immense quantities of the ponderosa pine. The net result of the policy governing the protection and use of these lands is a tendency toward less effective protection of watershed values.

Much true timberland in the Oregon and California grant lands has been classed by statute as agricultural land, and some of this, although unsuited to agricultural crop production, as a result of this classification has passed to private ownership, usually to be abandoned when the timber has been cut.

In a region of such steep slopes, high precipitation, and deep snows as that west of the Cascades, a high, dense forest cover, such as that formed by the existing coniferous stands, is essential to retard run-off, hold the soil in place, and prevent avalanches. The high timber values per acre of the virgin forest have resulted in large private holdings. Private lands are rapidly being cut over, and after cutting are largely devastated by fire. There is considerable doubt, therefore, whether the watershed requirements of these drainages as a whole will be adequately safeguarded if conditions continue as they are or become worse, as they can easily do. Public agencies should acquire about 5,000,000 acres of the private land on steep slopes. Approximately 100,000 acres of devastated forest lands should be replanted. Research is needed to determine how the forest cover of the Pacific Cascade slope can be made most effective in watershed protection and what use of the forest can be combined with maintenance of satisfactory watershed conditions.

## SUMMARY AND CONCLUSIONS

The foregoing discussion has presented a picture of watershed conditions as they exist in the United States today. In view of the fact that the program necessary to correct the watershed troubles of the country is so intimately related to the conclusions, it has seemed best to combine the two. Accordingly, the reader is referred to the section "A Watershed Protection Program."

# A WATERSHED PROTECTION PROGRAM

By L. F. WATTS, Director, Northern Rocky Mountain Forest and Range Experiment Station; E. N. MUNNS, Chief, Division of Silvics; W. R. CHAPLINE, Chief, Division of Range Research; and LUTHER G. SCHNUR, Associate Silviculturist, Allegheny Forest Experiment Station

CONTENTS



## INFLUENCE OF FOREST COVER

That stream flow and erosion are greatly influenced by the kind and condition of forest and other vegetative cover has been shown in the section of this report entitled "Watershed and Related Forest Influences", hereafter called the "watershed description section." Profound changes, it is evident, have taken and are taking place in the regimen of our streams, and undesirable soil movement has taken and is taking place on great areas of watershed land. These changes, usually harmful in their effect, have been shown to be largely the result of improper use of forest, range, and farm land.

The introduction to the watershed description section has shown that the degree of a forest's influence on watershed functioning depends on (1) the type and condition of the forest, (2) the characteristics of the soil, (3) the topography, and (4) the intensity and purpose of water use. A classification of the forest areas of the United States as to watershed-protective value, on the basis of these factors, is presented in table 1 and figure 1.

Almost three fourths of the total forest area has been classified as watershed-protection forest, that is, as having major or moderate influence on watershed values. The remaining fourth, because of flat topography or extremely permeable soil or for other reasons, is considered to have slight influence or none. Of the watershed-protection forest about two thirds, or 308 million acres, exerts a major influence and one third, or 141 million acres, exerts a moderate influence.

TABLE 1.—*Watershed-protective value of forests in the United States*

| Drainage | Total land area | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|---|
| | | | Major | Moderate | Slight or none |
| | *Thousand acres* | *Thousand acres* | *Thousand acres* | *Thousand acres* | *Thousand acres* |
| East: | | | | | |
| Northeast | 78, 428 | 42, 725 | 17, 320 | 13, 387 | 12, 018 |
| South Atlantic | 62, 812 | 43, 581 | 29, 204 | 6, 412 | 7, 965 |
| East Gulf | 105, 388 | 73, 313 | 18, 709 | 4, 335 | 50, 269 |
| West Gulf | 123, 926 | 36, 736 | 2, 921 | 20, 678 | 13, 137 |
| St. Lawrence | 84, 616 | 42, 246 | 5, 029 | 4, 112 | 33, 105 |
| Hudson Bay | 24, 960 | 6, 400 | 66 | 81 | 6, 253 |
| Total | 480, 130 | 245, 001 | 73, 249 | 49, 005 | 122, 747 |
| Mississippi River Basin: | | | | | |
| Upper Mississippi | 119, 586 | 28, 094 | 5, 694 | 4, 429 | 17, 971 |
| Ohio River | 130, 421 | 45, 391 | 35, 919 | 7, 569 | 1, 903 |
| Missouri River | 327, 447 | 28, 642 | 20, 515 | 6, 769 | 1, 358 |
| Arkansas-Red | 176, 981 | 52, 220 | 34, 560 | 15, 525 | 2, 135 |
| Lower Mississippi | 33, 720 | 17, 854 | 6, 857 | 1, 877 | 9, 120 |
| Total | 788, 155 | 172, 201 | 103, 545 | 36, 169 | 32, 487 |
| West: | | | | | |
| California | 70, 744 | 29, 780 | 21, 056 | 3, 736 | 4, 988 |
| Colorado | 154, 880 | 45, 070 | 36, 196 | 8, 829 | 45 |
| Rio Grande | 108, 160 | 17, 460 | 14, 168 | 3, 292 | ---------- |
| Great Basin | 138, 455 | 19, 534 | 5, 513 | 12, 021 | 2, 000 |
| Columbia | 131, 119 | 59, 025 | 38, 745 | 18, 180 | 2, 100 |
| Pacific Cascade | 31, 648 | 26, 487 | 15, 564 | 9, 509 | 1, 414 |
| Total | 635, 006 | 197, 356 | 131, 242 | 55, 567 | 10, 547 |
| Grand total | 1, 903, 291 | 614, 558 | 308, 036 | 140, 741 | 165, 781 |

The fact that the extent and character of the forest cover, as well as stream flow and erosion, are controlled in part by the quantity and distribution of precipitation makes it difficult to draw deductions from gross acreages such as are given in table 1. It may be noted that in the Pacific Cascade drainages, with steep slopes and heavy rainfall but with about 90 percent of the total area in forest, mostly dense, floods and erosion are no great cause for concern, while in the Colorado River Basin, with much lower rainfall but with less than one third of its area in forest of a lighter type, floods and erosion are serious. More localized comparisons are given in the watershed description section. The effect of forest destruction on run-off is indicated by studies at the Red Plains Erosion Experiment Station in Oklahoma, where a plot from which the forest litter had been burned produced more than 100 times as much run-off as a similar unburned plot; its effect on erosion is indicated by a study of Hoyt and Troxell in California, in which the flood flows from burned watersheds were found to contain 20 to 67 percent of ash and silt.

The Great Basin, with only 14 percent of its area forested and only 28 percent of this classed as of major influence, developed a serious flood and erosion situation only after the forest and other vegetative cover was reduced by overgrazing and fire. Similarly, in the Ohio River Basin, 35 percent of which is in forest, the silting problem and increased frequency of floods have followed misuse of the land by man.

Erosion is a geologic phenomenon older than the hills, yet in each region the original vegetative cover was usually sufficient for soil building. Reduction of the cover through timber cutting, fire, over-

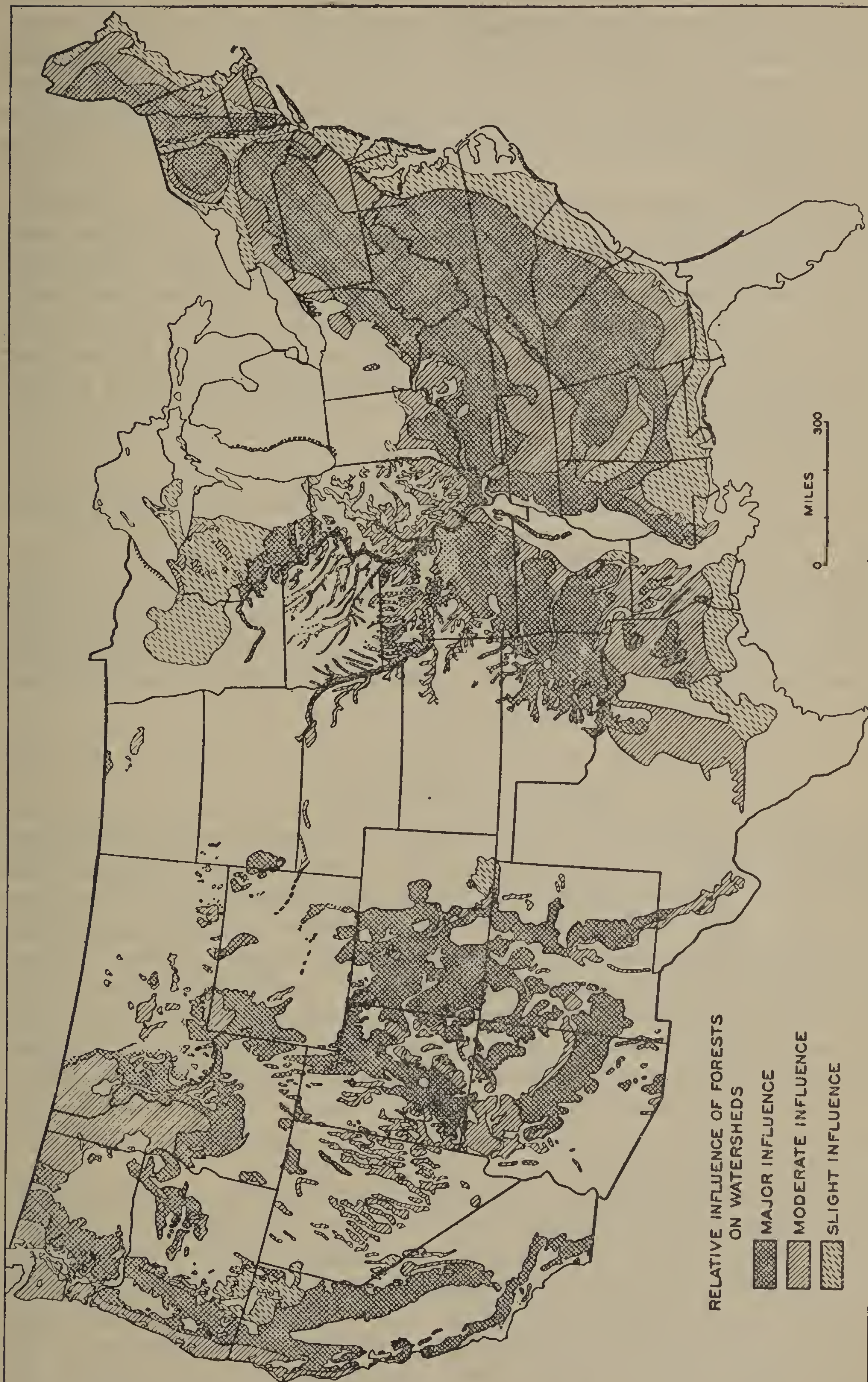


FIGURE 1.—Forests of slight, moderate, and heavy influence on watershed protection. The "breaks" and "badlands" not shown.

168342°—33—vol. 2——30

grazing, and cultivation has often not only prevented soil building but diminished the fertility of the existing soil and impaired its ability to produce cover of the original type. This condition is illustrated by data from an area in Mississippi studied by the Southern Forest Experiment Station where 23 tons of topsoil per acre were lost from cultivated land as compared to only a trace of soil lost from forest land. Erosion cannot be completely stopped, but by restoring forest or other vegetative cover on the steeper and more critical areas the process can be retarded to a rate less than that at which fertility is added to the soil.

In each of the major drainage basins, bad conditions of stream flow and erosion now exist. On an immense area the forest cover has been reduced or removed by fire and improper cutting. The vegetative cover has too often been depleted by improper grazing methods, and the fertile topsoil has been washed from millions of acres of agricultural lands. The result of this land treatment has been higher and more frequent floods, silted reservoirs and stream channels, accentuated difficulties during periods of low water, and reduced productivity of the land.

## RELATION OF OWNERSHIP TO WATERSHED CONDITIONS

Land ownership, more than any other one factor, has determined the differences in present watershed conditions. The degree to which watershed requirements have been met on land in various types of ownership and the sort of action necessary to establish satisfactory watershed management in each of these types are substantially as follows:

### PRIVATE

#### AGRICULTURAL LAND

In the eastern half of the United States the most acute stream-flow and erosion problems exist on land now classed as agricultural. On such land, according to rough calculations, perhaps 70 percent of the erosion takes place and 40 percent of the water troubles originate. As has been pointed out in the section of this report entitled "Agricultural Land Available for Forestry", more than 50 million acres of agricultural land in the United States is now abandoned or idle, and present trends indicate the abandonment of an additional 25 or 30 million acres in the next 20 years. Largely because of removal of fertile topsoil, often through sheet erosion, the productivity of nearly all the land now abandoned was reduced below the point at which the land could be used economically for crop production.

Sheet and gully erosion on agricultural land are by no means confined to abandoned land and land approaching abandonment. Under present cropping methods erosion is the usual condition, and unless present practices are remedied more and more of the fertile soil from farm lands generally will be added to the silt load of our streams and rivers. On land suited for agricultural use, the problem is one to be solved by agriculture rather than by forestry. The Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering, individually, in cooperation with States, are working on the agricultural land phases of the erosion problem. Further reference here to the control of erosion on agricultural land will be omitted.

Among the worse situations as regards erosion are those described in detail for the South Atlantic drainages, where at least 5 million acres out of a total of 46 million acres of farm land is so seriously eroded that cropping must be discontinued; the Yazoo River silt loam uplands of the lower Mississippi River drainage, where 783,000 acres out of a total of about 2½ million acres of crop land is being seriously eroded; and the glaciated section of Illinois, where about 7½ million acres out of a total of 31 million acres is in a similar condition. The same condition exists on smaller portions of most of the eastern drainages.

These conditions are in part the result of cultivation on slopes so steep and soils so erosive that destructive washing was inevitable. Failure to hold the soil on lands that could have remained in agriculture by contour plowing, terracing, and proper crop rotation has been another contributing factor. We are now faced with the problem not only of putting this once productive land to use but also of preventing it from doing positive damage through increased contribution to run-off and through the silting of stream channels. That this land does accentuate these two problems immensely is shown by many experimental results reported in the watershed description section of this report.

Since private ownership did not meet watershed requirements on these lands even while they had agricultural value, obviously it can not be expected voluntarily to assume the expense of rehabilitating any great part of the lands or of controlling erosion and stream flow from them. The situation calls for public acquisition and management of areas that can be blocked up into feasible administrative units and of smaller units where the silt contribution is extremely large and where private initiative plainly can not be expected to correct conditions. Small isolated tracts normally should be taken care of in private ownership with some degree of public aid. Public acquisition can come in part through tax delinquency and in part through gift or purchase. In any event the cost per acre should not be high. The area of lands once farmed that should be repossessed by the public is believed to be almost 22 million acres.

On a large part of this land a cover of grass, weeds, brush, and trees sufficient to hold the soil will come in naturally if cropping is permanently eliminated and the cover is protected from fire and overgrazing, but on some 10 or 11 million acres in more humid regions the gullying that has started can best be stopped by planting trees.

## FOREST LAND

Private ownership of forest land has usually carried with it no consciousness of an obligation to manage the lands so as to maintain or improve watershed conditions. In cutting timber it has generally been the owner's purpose to harvest the existing timber and dispose of the cut-over land as soon thereafter as possible. The section of this report entitled "Current Forest Devastation and Deterioration" has stated that about 10 million acres of private timberland is cut over annually. Only a small part of this is cut in such a way as to bring about perpetuation of the forest. Cutting practices designed to promote natural reproduction have been adopted on only about 10 million of the 444 million acres of privately owned forest lands. That

present owners do not intend to retain possession permanently is implied by the fact that, even prior to the present depression, great areas of cut-over land in the Lake States, the South, the Pacific Coast, the northern Rocky Mountains, and other regions had become tax delinquent.

Too often, logging methods have been used that were extremely damaging to young growth left standing and that induced rapid run-off and erosion. Broadcast burning of slash in the ponderosa pine and other types has been curtailed in recent years only.

Fire control on private timberlands is inadequate in all regions of the United States with the possible exception of the northern and southern Rocky Mountains. (See table 5 of the section of this report entitled "Protection Against Fire.") The best available data show that only about 54 percent of the 412 million acres of private timberlands needing protection are receiving it. More than 150 million acres of private forest land in the 11 Southern States and more than 35 million acres in the Central States receives no protection. Partly as a result of this fact, the area burned over annually in the 5-year period 1926–30 averaged more than 37½ million acres in the South and 1,379,000 acres in the Central States. Recently in some western regions there has been a tendency to withdraw protection from cut-over lands where such action does not jeopardize virgin timber.

Grazing on private timberlands has likewise failed to meet watershed requirements. In the East, grazing use of woodlands has often been so heavy as to destroy the litter cover, pack the soil, and prevent the establishment of young trees in the stand. The watershed description section has shown that this treatment increases run-off and in some instances causes erosion. In the West, where range forage on timberland is usable it has been sold without serious attempt to regulate use in such a way as to maintain the vegetative cover. The proportion of the 228 million acres of privately owned forest land used as pasture on which watershed management receives even incidental consideration is insignificant.

Partly as a result of the practices just mentioned, about 56 million acres of privately owned forest land in the United States has been devastated. The Lake States with 12 million acres, the South with 23 million acres, and the Northeast with 5 million acres of such devastated land clearly illustrate the lack of concern for forest values.

So long as the treatment of private land does not damage other land, or the public, public intervention is not called for. Where bad management will result in irregular stream flow, floods, erosion, or silting, or otherwise damage public or private property, certainly management restrictions are justified. They cannot properly be applied, however, unless the public is willing to bear its share of the expense which such action may entail. As an alternative to regulation the only recourse seems to be public acquisition of critical watershed areas. This is discussed in detail in the section of this report entitled "Public Regulation of Private Forests." It is estimated that approximately 155 million acres of major-influence watershed land should be acquired by the public in order to safeguard public welfare. The distribution of this land by regions is shown in table 9.

The importance of privately owned forest land to watershed protection is shown in table 2. Certainly, with a total of 297 million acres of privately owned forest land classified as of high and moderate watershed influence, the condition of such land is a matter of public concern.

TABLE 2.—*Watershed-protective influence of privately owned forests*

| Drainage | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *Acres* | *Acres* | *Acres* | *Acres* |
| Northeastern | 38, 587, 000 | 14, 544, 000 | 12, 601, 000 | 11, 442, 000 |
| South Atlantic | 42, 137, 000 | 28, 444, 000 | 5, 913, 000 | 7, 780, 000 |
| East Gulf | 72, 187, 000 | 18, 480, 000 | 4, 248, 000 | 49, 459, 000 |
| West Gulf | 36, 588, 000 | 2, 916, 000 | 20, 588, 000 | 13, 084, 000 |
| Lower Mississippi | 17, 842, 000 | 6, 847, 000 | 1, 877, 000 | 9, 118, 000 |
| Arkansas-Red | 48, 775, 000 | 32, 040, 000 | 14, 871, 000 | 1, 864, 000 |
| Ohio | 43, 532, 000 | 34, 268, 000 | 7, 429, 000 | 1, 835, 000 |
| Upper Mississippi | 26, 730, 000 | 5, 624, 000 | 4, 329, 000 | 16, 777, 000 |
| St. Lawrence | 34, 696, 000 | 4, 828, 000 | 2, 764, 000 | 27, 104, 000 |
| Hudson Bay | 5, 513, 000 | 66, 000 | 76, 000 | 5, 371, 000 |
| Missouri River | 14, 483, 000 | 12, 262, 000 | 1, 521, 000 | 700, 000 |
| California | 13, 753, 000 | 10, 009, 000 | 2, 086, 000 | 1, 658, 000 |
| Colorado | 6, 482, 000 | 2, 844, 000 | 3, 638, 000 | ---------- |
| Rio Grande | 7, 787, 000 | 6, 154, 000 | 1, 633, 000 | ---------- |
| Great Basin | 3, 851, 000 | 1, 856, 000 | 1, 497, 000 | 498, 000 |
| Columbia | 17, 189, 000 | 12, 438, 000 | 4, 743, 000 | 8, 000 |
| Pacific Cascade | 14, 225, 000 | 8, 576, 000 | 4, 781, 000 | 868, 000 |
| Total | 444, 357, 000 | 202, 196, 000 | 94, 595, 000 | 147, 566, 000 |

## TOWN, MUNICIPAL, AND COUNTY

Town and municipal forests, which total 473,765 acres in the United States, are in general very well cared for. Usually they have been established for watershed protection. They are policed and protected, and cutting and grazing are either banned or so regulated as to permit maintenance of favorable cover conditions. Denuded lands are usually planted as acquired.

While no attempt has been made to determine what acreage should ultimately be in municipal forests, it may be said that the area should be greatly increased. This is especially true of city watershed lands. The responsibility is localized and very direct. Often the acquisition and maintenance of a watershed area is no less definitely the responsibility of a city than the building of the conduit through which the water reaches the city mains.

In many sections of the United States large acreages of forest lands are reverting to the local governments for nonpayment of taxes. In most States these lands revert to the county; in a few they revert to the town or the State. For the sake of brevity they are all here considered as county land. Such lands are in both large and small blocks, and in most instances have been cut over, burned, or devastated. Where actually organized for administration these lands are satisfactorily handled. The greater part are not so organized and are given little attention other than fire protection. Particularly in agricultural districts, the land that has reverted or is reverting to the public is largely land that has been used for agriculture but that through one cause or another is no longer profitable for such use. In many cases, as has already been stated, erosion has been a primary cause of reversion.

These tax title lands, both forested and agricultural, often spoken of as the "new public domain", are returning to public ownership in a very poor watershed condition and frequently must be given special attention if they are to perform any worthwhile service. Most of them should not be returned to private ownership. They should be

blocked as public forests, and the public should assume the full responsibility of ownership. Trees should be planted on them if necessary, fire protection should be provided, and such practices as promiscuous cutting or too heavy grazing use should be prohibited.

Where the financial burden of properly caring for these lands is too heavy for the resources of the local government, the larger block at least should be taken over and managed by the State. Some of the lands are so located that it would be logical to include them in national forests or, where suitable, in national parks.

## STATE

State-owned forest lands total more than 13 million acres, including 4,395,549 acres of State forests, 2,682,509 acres of State parks, and 6,140,106 acres in other status.

In the Pacific Coast and Rocky Mountain States, State ownership generally goes back to Federal land grants made without regard to the major purpose which the land should serve. In New England and the Middle Atlantic States, State ownership has more often resulted from direct acquisition and in some instances is based in part on watershed-protection needs. In some regions, including the Lake States, State ownership has resulted in part through Federal grant, in part through purchase, and in part through tax delinquency. Obviously, in such cases watershed value was not the primary basis of selection. Table 3 shows by regions the watershed-protective influence of forest lands in State, municipal, and county ownership.

Table 3.—*Watershed-protective influence of forests on State, county, and municipal lands*

| Drainage | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *Acres* | *Acres* | *Acres* | *Acres* |
| Northeastern | 3, 545, 000 | 2, 500, 000 | 500, 000 | 545, 000 |
| South Atlantic | 232, 000 | 100, 000 | 82, 000 | 50, 000 |
| East Gulf | 250, 000 | 50, 000 | 5, 000 | 195, 000 |
| West Gulf | 148, 000 | 5, 000 | 90, 000 | 53, 000 |
| Lower Mississippi | 12, 000 | 10, 000 | | 2, 000 |
| Arkansas-Red | 105, 000 | 70, 000 | 14, 000 | 21, 000 |
| Ohio | 282, 000 | 150, 000 | 64, 000 | 68, 000 |
| Upper Mississippi | 1, 175, 000 | 70, 000 | 100, 000 | 1, 005, 000 |
| St. Lawrence | 5, 115, 000 | 200, 000 | 1, 328, 000 | 3, 587, 000 |
| Hudson Bay | 17, 000 | | 5, 000 | 12, 000 |
| Missouri | 411, 000 | 200, 000 | 163, 000 | 48, 000 |
| California | 121, 000 | 111, 000 | | 10, 000 |
| Colorado | 1, 797, 000 | 1, 200, 000 | 595, 000 | 2, 000 |
| Rio Grande | 1, 069, 000 | 1, 000, 000 | 69, 000 | |
| Great Basin | 122, 000 | 15, 000 | 5, 000 | 102, 000 |
| Columbia | 2, 021, 000 | 835, 000 | 1, 000, 000 | 186, 000 |
| Pacific Cascade | 1, 058, 000 | 500, 000 | 227, 000 | 331, 000 |
| Total | 17, 480, 000 | 7, 016, 000 | 4, 247, 000 | 6, 217, 000 |

Most State lands organized as State forests or parks are so managed and protected that watershed values are maintained and improved. In some Eastern States cutting is closely supervised, grazing is restricted, fire is virtually excluded, and most of the denuded areas have been planted. In some States, because of lack of interest in State forests, protection is inadequate, grazing and cutting are vir-

tually unregulated, and little if any progress has been made in reforesting denuded lands.

State-owned forest lands outside State forests and parks in some instances are given little or no administration. Many of these holdings are so widely scattered and in such small parcels as to make management somewhat difficult. In many of the Western States these lands are leased for grazing on an acreage basis without any restrictions as to numbers of stock to be pastured or season of use. In some instances timber is sold by estimate and cutting is not supervised. State lands inside national-forest boundaries, however, are often given protection and other management under cooperative agreements with the Forest Service. In some States there exists a State forestry organization capable of expanding sufficiently to place all State-owned forest lands under administration.

The acreage of organized State forests should be increased greatly. Much increase promises to come about through tax delinquency. An aggressive purchase and exchange program should be formulated to provide that the tax-reverted holdings will be consolidated for efficient management.

Since a large acreage of devastated forest land and submarginal agricultural land will inevitably find its way into State ownership, many of the forested States are faced with the necessity of financing a large program of reforestation and fire protection in order to rebuild watershed values. The division of responsibility for such activities among the various public agencies is discussed in some detail in the section of this report entitled "The Probable Future Distribution of Forest Land Ownership."

## FEDERAL

### NATIONAL FORESTS

On the national forests, a desirable type of administration is provided for a large area of forest and related wild land. As shown in table 4, the national forests with a net area of 140,003,966 acres, have 107,773,000 acres in forest. Of this forested area 70 percent has high watershed influence, 24 percent has moderate influence, and only 6 percent has slight or no influence. By far the greater part of this land is located in mountainous sections at the headwaters of major streams.

TABLE 4.—*Watershed-protective influence of national forests*

| Drainage | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *M acres* | *M acres* | *M acres* | *M acres* |
| Northeastern | 532 | 266 | 266 | |
| South Atlantic | 1,057 | 640 | 417 | |
| East Gulf | 757 | 80 | 82 | 595 |
| Arkansas-Red | 2,569 | 2,450 | 69 | 50 |
| Ohio | 1,276 | 1,200 | 76 | |
| Upper Mississippi | 189 | | | 189 |
| St. Lawrence | 1,810 | 1 | | 1,809 |
| Missouri | 9,166 | 6,103 | 3,000 | 63 |
| California | 13,127 | 9,466 | 1,500 | 2,161 |
| Colorado | 21,913 | 19,870 | 2,000 | 43 |
| Rio Grande | 5,364 | 4,864 | 500 | |
| Great Basin | 6,670 | 3,000 | 2,670 | 1,000 |
| Columbia | 34,755 | 22,000 | 11,933 | 822 |
| Pacific Cascade | 8,588 | 5,188 | 3,400 | |
| Total | 107,773 | 75,128 | 25,913 | 6,732 |

Fire protection is given all national-forest lands, although in some regions it has not reached a satisfactory standard. The action necessary to meet the minimum standards is discussed in detail in the section of this report entitled "Protection Against Fire." In the 5-year period 1926–30, for the entire national-forest system the area actually burned over was only 7 percent more than the allowable burn; in the Middle Atlantic States and Pacific Coast States, however, the acreage burned was 3.8 times and 2.8 times, respectively, as great as the allowable acreage, and on about 30 million acres of critical areas in the South, Pacific Coast, and Northern Rocky Mountain Regions the area burned was about five times as large as that which could be accepted as satisfactory.

Timber cutting on the national forests is usually handled on the selection system, which is most satisfactory from a watershed standpoint. In certain types, particularly the Pacific Coast Douglas fir and mature western white pine, the present cutting practice is not entirely satisfactory from a watershed-protection standpoint, but the condition of the virgin stand being cut seems to demand that the present practices be continued. Fortunately in both instances, owing to the humid climate, as discussed in the watershed description section, rather complete revegetation follows cutting very quickly.

Denuded lands are being planted as rapidly as funds will permit. Planting operations to date have covered more than 300,000 acres, and the program now outlined calls for the planting of 2,100,000 acres in the next 20 years. This work is progressing slowly and should be greatly speeded up.

National-forest range lands as a whole are safeguarded from improper use, although in some places grazing practices do not adequately safeguard watershed values or permit the vegetation rapidly to reclaim lands injured before the forests were established.

On the whole, national-forest administration takes into account the needs of watershed protection and in a very practical way applies the available information as to protection of watershed values. Administration is constantly improving, and it is reasonable to expect that the national forests will continue to exert an increasing beneficial influence upon soil and water conditions. As is shown in the section of this report entitled "Research in the United States Forest Service", much research is needed to determine definitely the best methods of handling watershed lands. The national forests, including most of the conditions to be studied, provide an excellent field for this work.

That the acreage of national-forest land must be greatly increased if watershed values are to be preserved is clear. The benefits from watershed protection are largely public, and it cannot be expected that private ownership will bear the burden of proper management unless it pays immediately. In most cases, local governments cannot be expected to finance projects of interstate or national significance. The most desirable division of ownership among agencies is discussed in detail in the section entitled "The Probable Future Distribution of Forest Land Ownership."

## INDIAN LANDS

Lands in Indian reservations are not, on the whole, given the best possible management from a watershed standpoint. The objectives

of timber management are substantially the same as on the national forests. Fire control has been seriously handicapped by lack of adequate funds. Steps have been taken to correct the serious overgrazing which has been practiced on some reservations. The indeterminate status of Indian lands, discussed in the section of this report entitled "The Indian Forests", is chiefly responsible for defects in management. As is shown by table 5, of the 15 million acres of Indian forest land nearly 70 percent is classified as having high watershed influence.

TABLE 5.—*Watershed-protective influence of forests on Indian lands*

| Drainage | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *M acres* | *M acres* | *M acres* | *M acres* |
| Ohio | 56 | 56 | | |
| St. Lawrence | 410 | | 20 | 390 |
| Hudson Bay | 870 | | | 870 |
| Missouri | 1,490 | 730 | 460 | 300 |
| California | 985 | 102 | 150 | 733 |
| Colorado | 8,493 | 7,797 | 696 | |
| Rio Grande | 400 | 350 | 50 | |
| Great Basin | 10 | 10 | | |
| Columbia | 2,225 | 1,725 | 250 | 250 |
| Pacific Cascade | 480 | | 480 | |
| Total | [1] 15,419 | 10,770 | 2,106 | 2,543 |

[1] This figure includes some 6,772,000 acres of noncommercial forest, mostly of the piñon-juniper type in Arizona and New Mexico.

## NATIONAL PARKS AND NATIONAL MONUMENTS

National parks and monuments are generally handled in a way that meets watershed requirements. Commercial use of all kinds is greatly restricted, and in only a very slight degree is this regulated use at variance with best watershed-protection practices. Grazing is gradually being excluded. Commercial cutting is entirely excluded. Fire protection in most of the parks is now of about the same standard as that on the national forests. More than 90 percent of about 4½ million acres of land in national parks and monuments has major or moderate watershed influence, as is shown in table 6. Watershed conditions on these lands are good and are rapidly improving.

TABLE 6.—*Watershed-protective influence of forests on national park and monument lands*

| Drainage | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *M acres* | *M acres* | *M acres* | *M acres* |
| Northeastern | 12 | 10 | | 2 |
| Arkansas-Red | 1 | | 1 | |
| Ohio | 220 | 220 | | |
| Missouri | 1,654 | 154 | 1,500 | |
| California | 828 | 828 | | |
| Colorado | 387 | 387 | | |
| Rio Grande | 20 | | 20 | |
| Columbia | 1,059 | 600 | 109 | 350 |
| Pacific Cascade | 239 | 100 | 139 | |
| Total | 4,420 | 2,299 | 1,769 | 352 |

## PUBLIC DOMAIN

Conditions on the unreserved and unappropriated public domain are in decided contrast to those on the classes of Federal lands just discussed. The best available estimates show that 25 million acres of the 173,318,246 acres of the public domain and the Oregon and California Railroad and Coos Bay Wagon Road grant lands is forested. Of the forested land 91 percent has moderate or high protective influence, as is shown in table 7.

TABLE 7.—*Watershed-protective influence of forests on public domain and other Federal lands* [1]

| Drainage | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *Thousand acres* | *Thousand acres* | *Thousand acres* | *Thousand acres* |
| Northeastern | 49 | | 20 | 29 |
| South Atlantic | 155 | 20 | | 135 |
| East Gulf | 119 | 99 | | 20 |
| Arkansas-Red | 770 | | 570 | 200 |
| Ohio | 25 | 25 | | |
| St. Lawrence | 215 | | | 215 |
| Missouri | 1,438 | 1,066 | 125 | 247 |
| California | 966 | 540 | | 426 |
| Colorado | 5,998 | 4,098 | 1,900 | |
| Rio Grande | 2,820 | 1,800 | 1,020 | |
| Great Basin | 8,881 | 632 | 7,849 | 400 |
| Columbia | 1,776 | 1,147 | 145 | 484 |
| Pacific Cascade | 1,897 | 1,200 | 482 | 215 |
| Total | 25,109 | 10,627 | 12,111 | 2,371 |

[1] Including Oregon and California and Coos Bay land grants.

The condition and management of these lands are discussed in detail in the sections of this report entitled "The Public Domain and Other Federal Forest Lands" and "Forest Ranges." These lands are without administration or purposeful management. They suffer from all the evils of improper grazing use, and where timber cutting takes place no provision is made to prevent devastation. Fire protection is entirely lacking on a large part of the watershed lands, and where given is adequate.

Slightly more than 19 million acres of these lands, because of location and character, might logically be added to existing national forests. An additional area in excess of 3 million acres might well be given national-forest status as new units or held for inclusion in the national forests at a later stage in the national-forest acquisition program. Administration of these lands as portions of national forests would increase the stability of the livestock industry and thus greatly encourage better handling of intermingled or nearby private land, thus making watershed management more effective generally. The bulk of these lands should be included in public grazing reserves and given such administration as would preserve and improve the watershed values.

The proper administration of these lands would promote improvement of watershed conditions in the West perhaps more than any other single measure.

The watershed-protective value of forests in all ownerships is summarized in table 8.

TABLE 8.—*Watershed-protective value of forests in the United States by ownership*

| Ownership | Total forest area | Forest area by watershed-protective influence | | |
|---|---|---|---|---|
| | | Major | Moderate | Slight or none |
| | *Thousand acres* | *Thousand acres* | *Thousand acres* | *Thousand acres* |
| National forests | 107,773 | 75,128 | 25,913 | 6,732 |
| Indian forests | 15,419 | 10,770 | 2,106 | 2,543 |
| National parks and monuments | 4,420 | 2,299 | 1,769 | 352 |
| Public domain and other Federal land | 25,109 | 10,627 | 12,111 | 2,371 |
| State, county, and municipal | 17,480 | 7,016 | 4,247 | 6,217 |
| Private | 444,357 | 202,196 | 94,595 | 147,566 |
| Total | 614,558 | 308,036 | 140,741 | 165,781 |

## MAJOR CRITICAL SITUATIONS

A single watershed problem may be common to parts of several drainages. For example, watershed conditions in the piedmont and upper coastal plain sections from the Potomac River around the Atlantic seaboard to Texas form a single problem, and so do those in the semiarid woodlands throughout the West. In order to avoid repetition, statements as to major critical watershed situations will be based on representative groups of conditions rather than on the drainage divisions previously used. No attempt will be made here to cover the entire country or to present statistics in such a way as to make possible a summation into national totals.

### MISSISSIPPI BLUFF LANDS AND SILT LOAM UPLANDS

The bluff lands of the Mississippi River and the lower reaches of its main tributaries form a narrow belt extending from New Orleans to St. Paul, through the lower Mississippi, Ohio, Missouri, and upper Mississippi River drainages. They are the steep, broken slopes and adjacent silt loam uplands that flank the river terraces. They total about 20 million acres, of which two thirds lies below the mouth of the Missouri River, and are characterized by windblown and silt loam soils.

These bluff lands are believed to contribute more to the silt problem of the Mississippi River than any other area of the same size. The greatest watershed problem here is erosion, although flood control is almost equally important. The high erosibility of the soils naturally favors the formation of deep gullies, which spread with exceptional rapidity and are most difficult to check. This is particularly true in the Yazoo River uplands, in the southern tip of Illinois, and in the bluff lands of southwestern Wisconsin and of adjoining areas in Minnesota, Iowa, and Illinois. In some counties of the Yazoo uplands as much as 40 percent of the area is badly gullied, the gullies reaching in many cases to a depth of 20 or 40 feet and in some cases to more than 100 feet.

Originally almost unbroken, the forest stands have been reduced by fire, grazing, lumbering, and clearing for agriculture by approximately 75 percent in the South and by an even greater proportion in the North.

The erosion problem here is very largely the consequence of improper agricultural practices. It has resulted in part from cropping land that never should have been cleared and in part from using improper cropping methods on good agricultural land. Principally as a result of these two practices about one sixth of the agricultural area has already been abandoned and active erosion is continuing on about one fourth of this abandoned land.

Special measures to check erosion are needed now on upwards of 1 million acres of the bluff lands, and unless present bad practices are quickly corrected will be needed on an even larger area. The volume of soil being eroded from these areas each year is inconceivable. A single rain on experimental plots near Holly Springs, Miss., for example, removed soil at the rate of 23 tons per acre from cultivated land with a 10 percent slope. Studies in southwestern Wisconsin have resulted in an estimate that an area of 10,000 square miles in Wisconsin and Minnesota contributes 15 million tons of silt to the Mississippi River annually. In both sets of experiments erosion from forested soils was insignificant compared with that from barren or cultivated soils. While these figures may or may not be extreme, they establish clearly the importance of erosion control on bluff lands if the Mississippi River silt problem is to be solved.

The same studies showed the effectiveness of the forest cover in controlling run-off. The percentage of the precipitation that ran off immediately from cultivated plots as compared with that from forested plots was about 130 times as large in Mississippi and about 12 times as large in Wisconsin.

The situation on forested lands, while far from satisfactory, is in general not wholly bad. Particularly in the South, fires occur commonly in the bluff lands and destroy the leaf mold and litter so necessary to watershed protection. In the State of Mississippi as a whole the acreage burned over annually averages more than 40 times the allowable burn. The percentage burned in the bluff lands is not much below the State average. Timber cutting, while usually falling short of devastation, has been too heavy to permit the forest to exert its full watershed-protective influence, and grazing has injured the forest cover on many areas.

Solution of the erosion and flood problems of the bluff lands, essential both locally and nationally, appears to require (1) lifting from agricultural use land that is submarginal for that use; (2) reforesting, by planting, the 650,000 acres of land on which erosion will otherwise continue; (3) providing adequate fire protection on timberlands; and (4) installing special mechanical erosion checks where necessary.

There is little hope of obtaining proper watershed conditions on this land in private ownership, because the expense incidental to proper management will not be returned as a direct financial profit to the individual owner. To obtain such conditions will necessitate public acquisition of a large acreage of submarginal farm and forested land. On the timberlands that remain in private ownership, fire protection should be materially strengthened, through public aid and extension.

The damage that results from conditions within this narrow belt along the river obviously is of national interest. The navigability of the river, its interstate character, and the magnitude of the Mississippi flood problem call for national action. Individual States affected should, of course, assume part of the direct responsibility, but the major part of the control program should and must be carried by the Federal Government.

### PIEDMONT AND UPPER COASTAL PLAINS

Erosion and floods are the two outstanding watershed problems in the piedmont and upper coastal plain sections, which include the critical situation not only in the southern Atlantic drainages but in the east Gulf drainages as well. The serious conditions are largely confined to the highly erosible deep clay to loam soils of the piedmont and the somewhat similar soils found on parts of the upper and more hilly portion of the coastal plain. Rainfall is abundant, varying from about 35 inches in the upper Potomac to 80 inches farther south. As much as 22 inches of rainfall has been recorded in an individual storm.

The forest cover, originally almost complete, now extends over only about two thirds of the total area, the forested proportion varying among the larger drainages from 50 percent to 75 percent. Organized fire protection has been provided for only a small part of the forest, and in the 5-year period 1926–30 the average annual burn for the States included was nearly 15 times the allowable burn.

The major problem has to do with the land that has been cleared and used for agriculture. With as much as 80 percent of the land in the charge of tenants, largely irresponsible, cropping has not been handled skillfully. Fields have been plowed up and down hill instead of along the contour or in terraces; cotton, corn, and tobacco have been grown under clean tillage year after year, the soil being left without cover during the period of greatest rainfall. Reduction of productivity by sheet erosion and destruction of productivity by deep gully erosion have resulted in widespread land abandonment. Within the east Gulf and South Atlantic drainages at least 8½ million acres of land has been abandoned in the past 20 years, and present trends indicate that abandonment may reach 12 million acres by 1950.

Fortunately the climate and the ease with which the southern pines reproduce favor rapid revegetation of abandoned land. It is believed that as much as two thirds of the abandoned land may be reclaimed by natural forest or by weeds and grass if left undisturbed. This would reduce to perhaps 2½ or 3 million acres the area demanding treatment within the next 20 years if erosion is to be controlled. On this area tree planting is the logical solution.

It will be difficult to obtain on privately owned forest the type of management that will adequately meet the erosion and stream-flow situation. It will be practically impossible under private ownership to carry through a program of reforestation and engineering works on idle land such as the situation demands unless the public pays the costs. For the Government to attempt to control the clearing and cultivation of lands that if so treated would be subject to destructive erosion would be impractical so long as the lands remained in private ownership.

Public acquisition and management of a large part of the eroding farm lands and the major-influence forest land appears to be the only adequate solution. Heavy Federal participation in this project is fully justified by the effect of the present situation on the maintenance of navigable rivers.

## CENTRAL STATES ABANDONED FARM LANDS

Abandoned farm lands of the Central States region, although in many sections intermingled with true forest land, constitute a watershed situation that requires special consideration. Conditions vary greatly among different parts of the region. In general, the unglaciated and therefore more hilly areas are most in need of attention. Elsewhere in these States soil depletion and erosion may be a serious matter but it is a problem for agriculture to solve, with forestry playing only a minor part through reforestation of small critical areas and through better management of farm woodlands on many farms.

The sections where conditions are most critical and where forestry may aid materially (outside of the Mississippi River bluff lands, discussed separately) include West Virginia, western portions of Kentucky and Tennessee, southern parts of Indiana, Ohio, Illinois, and Missouri, and, to a lesser degree, northern Missouri, southern Iowa, and eastern Nebraska and Kansas.

Within the sections where erosion is most acute perhaps 15 million acres of farm land has already been abandoned and the trend has apparently only gotten under way. The major reasons for abandonment, apart from the present economic situation as it applies to farm lands, are (1) the clearing for agriculture of land that owing to steep slopes or naturally shallow or highly erosible soils should have remained in forest, and (2) failure to apply special treatment such as contour plowing, terracing, and proper crop rotation to land, the agricultural usefulness of which might thus have been preserved. On many areas erosion continues unchecked after abandonment, while on other areas idleness permits the establishment of a cover of weeds, grass, brush, or trees sufficient to hold the soil.

Decisive action is justified by average annual flood damage amounting to more than $4,000,000 on the Tennessee and Ohio Rivers and to much greater sums on the Mississippi River proper, by the silting of navigable streams to correct which literally hundreds of millions of dollars have been spent or are proposed for expenditure, and by the serious domestic water supply problem encountered during periods of drought.

At present practically the whole area, except land that has reverted to public ownership through tax foreclosure, is in private ownership. Certainly private owners cannot logically be expected to spend money to cure a condition on lands that they have abandoned, or when any benefits resulting from the treatment would accrue to the public rather than to the owners. Public financial aid or public acquisition is indispensible to progress. In many instances the financial aid needed would approach or might even exceed the value of the land itself. Therefore a program of public acquisition seems to be the practical way out.

Owing to the interstate character of the main streams and their relation to navigation and flood control the problem is national in

scope, although some of its local aspects place responsibility on various public agencies in the several States. Certain of the States have enormous wealth, while others find it difficult to finance the usual functions of government. Some of the most critical situations are so located at the borders of States that, however important nationally, they have only minor significance for the State.

Obviously each agency involved should make the maximum equitable contribution. Private owners should handle situations in the farm-woodland class involving only a small part of their entire property; counties and municipalities financially able to do so should participate on areas not subject to blocking up for more specialized management; States should carry a large part of the burden, on the basis of responsibility for damage originating within their jurisdiction; finally, the Federal Government should assume the responsibility for large areas and for special conditions beyond the reach of local agencies.

With the dedication of these abandoned lands to watershed protection must go a planting program such as that set up in the section of this report entitled "Reforestation of Barren and Unproductive Land." Generally, planting should be concentrated at first on land that otherwise would continue to wash after cropping is eliminated. In very many cases this will mean only a small part of a farm otherwise in satisfactory condition. Farm-woodland planting is inexpensive, and besides contributing to watershed protection converts idle areas on the farm to a definite productive use. In most of the public planting timber production would be incidental to the benefits of erosion and flood control; it would be a real factor, nevertheless, in a region that imports great quantities of wood products. The use of land primarily for watershed protection usually need not eliminate timber cutting, game production, and recreational use.

Along with public acquisition and management must go improved fire protection on forest lands in all types of ownership.

## COASTAL DUNES

The coastal dunes include sand dune lands along the eastern shores of Lake Michigan and other Great Lakes and in places along the Pacific, Atlantic, and Gulf coasts. Of special interest are the dunes of Cape Cod, Long Island, the New Jersey coast, Maryland, North and South Carolina, Florida, and Oregon. These dunes menace harbors, transportation systems, agricultural lands, summer homes, and other improvements. The individual areas are small. Taken together they may compose a strip several miles wide along a thousand miles of coast line, totaling probably half a million acres.

At the present time a very small area of dune land is in public ownership. Part of this is in parks such as those in northwestern Indiana and at San Francisco. The greater part is in private ownership.

The control of sand movement on coastal dune areas will require planting grasses and shrubs, scattering litter and other humus material, building sand fences and traps, and reforesting by many different methods.

Fire control in the dune region is relatively simple, because the cover is usually insufficient to carry flames. After dunes have been stabilized, however, such a cover can be developed as will be subject

to destructive fires. On dune areas that are being stabilized, well-nigh perfect fire control should be maintained, because of the danger of loss of the cover.

In spite of the fact that their productive value is low, a considerable portion of the dune lands will be held for private development, largely as recreation areas or as estates. On such areas the use of fire should be closely restricted, cutting should be restricted to the removal of dead wood, and grazing use should be very closely restricted or entirely eliminated. Where feasible, dune lands should be taken into public ownership; only in exceptional cases can private ownership be expected to provide the type of management and protection required. Usually these areas have exceedingly high value for recreation, and the two purposes of soil fixation and recreation often can be served best through public control. Usually, Federal ownership should not be necessary.

## NORTHEASTERN DRAINAGES

The Catskill, Adirondack, Green, and White Mountain watersheds involve about 40 million acres of timberland in the northeastern drainages, including the St. Lawrence drainage below the Great Lakes. Here domestic and industrial water supplies are the major reasons for concern, because of unusually heavy concentrations of population. The metropolitan centers have a population of more than 15 million and require more than 2 billion gallons of water daily. Some 25 percent of the Nation's developed water-power capacity is in the Northeast, and the commercial tonnage shipped on the principal rivers of the region exceeds that on the Mississippi between New Orleans and Minneapolis. Flood control is likewise of great importance.

Originally this area was a continuous forest; at present only 54 percent of it is classified as forested, and a very large part of the forest that remains is badly deteriorated. Reduction of soil fertility by continuous cropping and by erosion from cultivated fields, and the settlement of better agricultural areas in the West, have caused the abandonment during the last two decades alone of more than 10 million acres of agricultural land in the northeastern drainages. Some sort of natural vegetative cover quickly establishes itself on cut-over land or abandoned farm land where the soil is not disturbed, preventing destructive erosion.

Because of the great value of the forests of these drainages as a source of metropolitan water supplies, and because of the navigability of many of the streams and their importance in the industrial and economic life of the region, much land in the rougher sections of New England and New York should be in public ownership. Great watershed-protection and recreational values would thus be maintained or increased. The States included have not only a great concentration of population but also in some cases a great concentration of wealth. Therefore the necessity for Federal assistance in watershed protection is less pronounced than in most other regions of the East. Certainly the Federal Government should at least acquire ample land to demonstrate proper management for watershed protection.

New York now owns 2½ million acres of watershed land and is acquiring an additional million acres. Some 350 cities of New York now own watershed forests. Cities and towns of Massachusetts own more than 25,000 acres of such forests; Newark, N.J., has a watershed

forest of 35,000 acres. Altogether, some 4½ million acres of forested watershed land in the region is in public ownership. This acreage should be increased very materially.

Private ownership of a large part of the watershed lands will and should continue. Timber values in this region, with proper management, make private forest-land ownership profitable, particularly on the more productive and more accessible sites. Fire protection, with public aid, is very nearly adequate. There is definite need, however, for a greatly expanded program of forest research and extension in order that timberland management may be improved.

## APPALACHIAN MOUNTAIN CHAINS

The Appalachian Mountain chains include the Allegheny and Appalachian Mountains, the Cumberland Plateau, and the Blue Ridge. They extend southwestward from New York to northern Georgia and involve some 50 million acres. They contain the headwaters of the Susquehanna, James, Ohio, Tennessee, and other important navigable rivers. Where the slopes and soils permit, farming is common.

The greatest watershed problem in this region is irregularity of steam flow. Erosion, also, is extremely serious, particularly on farmed lands. The forests have been cleared, unfortunately, from a large acreage entirely too steep and too erosible for profitable agricultural use. Cultivated fields with slopes of more than 30 percent are not unusual. Because of erosion, such land is ruined for agriculture by a very few years' cultivation. For this reason agriculture is declining and land abandonment is prevalent.

Originally the Appalachian Mountain chain was almost wholly forested. Almost all its forest land has now been cut over and many parts have been culled repeatedly. While the forest has so depreciated in quality that much of it now has little commercial value, the ground has reclothed with a cover sufficient to control erosion when fires are kept out. The fire-protection record for much of the area to date is bad and public interest in meeting the need for adequate protection is in general lacking. Those who have studied watershed conditions on the ground in the Appalachian Mountains consider improvement of the forest and other vegetative cover necessary as a means of controlling silting and reducing flood damage.

Here again the problem is complicated by ownership. There is no reason to expect private owners to correct conditions on practically worthless abandoned farm lands, and little more hope that they will adequately protect timberlands. Apparently the logical solution is public acquisition of a very large share of the high-influence forest and abandoned farm land. Because of the interstate character of the streams the Federal Government should carry the greater part of the burden. There is ample opportunity for both State and Federal ownership.

With a large area in public ownership and with adequate control of the use of fire on private lands the situation should improve rapidly.

## OZARK-OUACHITA

The Ozark-Ouachita area of Arkansas, Oklahoma, and Missouri includes the hilly to mountainous country of the lower Mississippi

drainage. While these mountains have an area of only 45 million acres, composing less than 6 percent of the Mississippi River drainage, they are estimated to yield more than 25 percent of the flood flows of the lower river. More than 50 percent of the peak flow of May 1, 1927, came from this section.

Agriculture in this region started with the more level stream bottoms and gradually expanded to include more and more hillside land, where rapid run-off and excessive erosion naturally followed. Much of this hillside agricultural land is now definitely submarginal and is being abandoned. Erosion, while not so spectacular as that of the Mississippi River bluff lands, is widespread on hill lands used for cultivated crops. On much of the land, fortunately, abandonment is followed rather promptly by the development of a cover of grass or, where seed is available, of forest.

The forest of mixed pine and hardwoods in the mountains and pure pine in the foothills originally was almost continuous. Repeated fires, local overgrazing, extensive lumbering, and clearing for agriculture have reduced the forest area to possibly one half its original size and deteriorated the remainder to a point at which its influence on run-off and on erosion is seriously impaired. Fires are exceedingly prevalent and prevent the maintenance of a good forest and litter cover. It is estimated that approximately one seventh of the major-influence watershed forests are burned over each year. Obviously, under such treatment good watershed conditions cannot exist.

Bad as conditions may be on the burned mountain forests, they are much more serious on the cultivated portion of the area. The more level cultivated lands can no doubt be maintained by proper cultivation methods, but the hillside fields must ultimately be abandoned. In some situations only a few crops can be raised before the top soil is sluiced off. Certainly this type of agriculture is not in the public interest and should be stopped.

A small part, about 1,250,000 acres, of these mountain forests is national-forest land. On these lands watershed protection is the primary purpose of management, and while conditions are not yet satisfactory they are improving. The condition of the very limited area of organized State forest is likewise improving. The rest of the land is in private ownership, and it is here that watershed problems are greatest.

Correction of the existing conditions depends on (1) improved fire protection and (2) proper management of major-influence forest and critical agricultural lands. Foresters and others personally familiar with conditions in these mountains substantially agree that erosion can be diminished and stream flow made more regular by improving the forest and vegetative cover. Public acquisition of major-influence land would aid in accomplishing this end.

The problem is so largely one of preventing floods and silting in the lower Mississippi River Basin that the responsibility is largely Federal. The States concerned should not be expected to carry any considerable part of the acquisition program. They should, however, take the lead in improving forest-fire conditions on private lands.

## BREAKS AND BAD LANDS

The Breaks and Badlands include more than 20 million acres on the Arkansas, Red, and Brazos Rivers to the south and on the

Missouri River to the north. These areas are characterized by steep, broken topography, extremely erosible and generally unproductive soil, low annual precipitation, and sparse vegetation ranging from grassland types to stunted, noncommercial tree growth. Much of the area is range rather than true forest land and is included in this report only because of the extent to which it contributes to the silt load of the Mississippi River and its tributaries and because many of the problems involved are common to watershed control on forest ranges generally. Erosion on these areas is great even under normal conditions and has been accentuated through misuse, largely overgrazing.

As a result of the low productivity of the soil, private ownership has not been attracted to this land. A high percentage of the area, except in Texas and Oklahoma, is in the public domain.

Erosion control here will be particularly difficult. Fire should be completely excluded, timber cutting should be restricted to dead and down timber or very light selective cutting at most, grazing should be greatly reduced and on many areas completely excluded, and where it is allowed the season of use should be carefully determined. Artificial revegetation with grass, brush, and trees will have to be studied and used where feasible. Finally, special engineering works to stop stream silting will have to be devised. Much research will be required on each phase.

Because of the restrictions in use required, obviously the situation can be corrected only under public ownership. This would mean acquiring lands now in private ownership, by purchase or exchange, and blocking them up with public lands into suitable administrative units. Federal rather than State control seems logical, because the silt contributions from these areas to the Missouri and Mississippi Rivers are of national rather than local concern. For example, the silt contribution to the Missouri River which comes from the Breaks in Montana is of little economic consideration in Montana, but is a real factor in States farther down the river. Placing the public domain under administration, as discussed in the section of this report entitled "Public Domain and Other Federal Forest Land", should result in active efforts toward solution of the watershed problem of the Breaks and Bad Lands. At best it will not soon be solved.

## PACIFIC SLOPE DENSE FORESTS

Climatic conditions on certain areas of the Pacific slope are such as to cause the establishment of extremely dense forests with an unusually rank understory of small trees, ferns, and other low vegetation. This condition is especially marked in the redwood forest of northwestern California, in the Douglas fir and the fog-belt forests of western Oregon and Washington, and in the white-pine zone of the northern Rocky Mountain region. Undoubtedly, in a virgin condition these dark forests exert the maximum influence on stream flow and on soil stability.

Damage by fire is excessive. Particularly in the Douglas fir and white-pine zones, these forests present one of the most difficult problems in forest-fire protection. Acceptable protection standards have not been met even on the national forests. Fortunately, a new vegetative cover is rapidly established even following complete

destruction of the forest by fire. Erosion, therefore, is not serious except in restricted local areas.

A large part of the white pine and Douglas fir forests is in private ownership and in general is being liquidated through exploitation as rapidly as possible. Apparently part of these lands will ultimately return to public ownership. Cutting on private land has not been designed to maintain watershed values, and this condition, coupled with the common occurrence of fire following logging, has markedly reduced the effectiveness of these forests in stream-flow regulation.

These dense forests are exceptionally productive, and therefore would justify intensive management for timber production. The correction of cutting practice and the improvement of fire protection to meet even minimum requirements for timber production would adequately protect watershed values involved. Certainly these two measures are justified.

## PONDEROSA PINE-LODGEPOLE PINE BELT

The broad classification ponderosa pine-lodgepole pine belt includes the greater part of the commercial and subalpine forests of the West, excluding, of course, the more dense forests of the Pacific slope previously discussed. It includes the ponderosa pine forest with its various mixtures, the extensive lodgepole pine forests, the Rocky Mountain Douglas fir and spruce-fir forests, and the subalpine mixtures usually found above the commercial timber zone. The influences exerted on watershed conditions by the different forest types in this usually more arid belt are essentially similar.

Within this belt most of the precipitation comes in the form of snow, so that to the other run-off regulating influences of the forest is added retardation of snow melt. In contrast with conditions in the dense forests of the Pacific slope, the vegetative cover if once destroyed is likely to be slow in reclothing the soil, a condition that, as previously stated, favors accelerated erosion and run-off. The greater part of the area is used as range for livestock. This use easily upsets the vegetative balance, thus seriously reducing the effectiveness of the watershed cover. (Complete exclusion of livestock, however, is usually neither necessary nor desirable.)

These forests are the source of the greater part of the water flow for irrigation, water power, and domestic and industrial use in the West. Streams originating in them are, to a great extent, depended upon for the irrigation of nearly 20 million acres of land on irrigated farms which are valued including all land, buildings, and equipment at $4,887,000,000; for water-power developments that on January 1, 1931, were estimated to have an installed capacity of nearly 5 million horsepower or about 32 percent of the total installed capacity in the United States; and for industrial and domestic water supplies for about 6 million people. It is not an overstatement to say that the economic existence of the West is the measure of the importance of these waters.

Fortunately a very high percentage of the area is in national forests, national parks, and Indian reservations, where, as has been stated, something approaching proper watershed management is provided. Perhaps 3 million acres of it is in the public domain, where no management is provided other than inadequate fire protection and where watershed conditions are extremely bad.

Private ownership of this type of forest land is generally not favorable to good watershed conditions. A large proportion of these lands were acquired either as a land speculation or with the purpose of exploiting the virgin timber. The practice of industrial forestry on a permanent basis is the exception, and privately owned cut-over lands are not generally in a satisfactory condition. Too heavy cutting, unnecessary destruction of young growth in logging, fires in logging slash, and improper grazing use, have occurred too often.

In this belt tax delinquency on cut-over lands is exceptionally heavy, and the desire on the part of the owners to dispose of such lands is nearly universal. Many of the counties are financially unable to accept the responsibility of ownership of cut-over lands, and the States have shown little inclination to take over such lands. Existing conditions strongly encourage a greatly enlarged program of Federal acquisition of this type of land, as is shown in the section of this report entitled "Public Acquisition of Private Lands as an Aid to Private Forestry."

These forests are especially suited to multiple use. Timber cutting, grazing, recreation, and watershed use all have a definite place. There is urgent need for much carefully conducted research to develop the facts of proper management so that these various uses may be properly correlated.

### SEMIARID WOODLANDS AND BRUSH LANDS

Throughout the West there is a belt usually below but sometimes intermingled with the commercial timber where, either because of the semiarid climate or of past treatment, the cover consists of scrubby timber or brush. This includes the chaparral and brush fields of California and the pinon-juniper, aspen brush, oak brush, and similar types. In these types the understory vegetation is generally sparse and is not easily maintained. The natural balance is finely drawn, and even slight changes in cover may give rise to an adverse watershed condition not easy to overcome. Annual precipitation is low, but individual storms are sometimes very intense. Snow storage on these areas is not heavy as a rule.

The major watershed problem is erosion, although floods and mud flows are locally important. These areas are most often the lower reaches of watersheds heading in the timber belt above, in which case the material eroded from them is fed into the stream channels from which water is obtained for irrigation, power, and domestic use. Less frequently, as in parts of southern California and of the Southwest, the woodland areas themselves are the main source of water for these uses.

Fire control is not particularly difficult except in California, although fires often are permitted to burn over large areas of brush fields. In parts of California, owing to steep slopes, the inflammable character of the brush, and the extreme drought conditions that normally occur during the summer season, fire is the major problem. Here torrential or merely heavy rains on areas denuded by fire result in heavy run-off and in great damage by floods and erosion. Where flood waters are spread out over settling areas for the purpose of raising the level from which water supplies can be obtained by pumping, fine eroded material tends to seal the soil in such a way as to make percolation difficult.

Almost all this area, with the exception of the dense brush fields of the south coast drainages of California, is used as range for livestock. Except on the national forests, national parks, and Indian reservations, the cover usually has been badly depleted through overgrazing and other improper range use and in some instances has been completely removed. The removal of the vegetation, the breaking up of the litter by trampling, and the mechanical disturbance of the top soil has brought about an increase in run-off and has resulted in serious erosion. The fertile top soil has washed away, leaving the land seriously reduced in productivity and much less retentive of rainfall. Floods are therefore common, silt is being sluiced into reservoirs and ditches, and in some instances such as that of the Salt Lake Valley and of southern California great damage to improved farms has resulted through the deposition of gravel and boulders carried by floods.

Owing to the semiarid climate, improvement of watershed conditions will be slow even under careful management. The mantle of humus and enriched top soil that is characteristic of a large part of this region is so thin as to be easily destroyed. The type of plant cover that these areas once supported depended in marked degree upon the high fertility of soil that has now been washed away.

A relatively small part of these lands is within national forests, national parks, and Indian reservations and a small additional area is being administered as city watersheds, particularly in southern California. Such areas are managed so as to maintain watershed values. The greater portion of these lands is in the public domain or in private ownership, and on this portion neither watershed nor range values are being maintained. Over large areas the quantity of forage produced now is less than half that originally produced.

The major step in correcting watershed conditions on these lands is extremely simple, yet in spite of at least two decades of pressure it has not yet been taken. The key to the solution is to place the public domain under proper administration. Proper management of public-domain lands together with the existing management of the national forests would encourage better management of privately owned range land and would therefore greatly improve conditions generally.

## PROGRAM FOR ADEQUATE WATERSHED PROTECTION

### LAND MANAGEMENT REQUIREMENTS

In order to meet the deficiencies in watershed protection that have just been presented the following major improvements in land management must be effected.

#### FIRE PROTECTION

Fire protection on watershed lands must be improved to meet the standards set up in the section of this report entitled "Protection Against Fire." This will mean giving organized protection to the 191 million acres of forest now unprotected and materially strenghtening protection on the units already organized. In particular, protection effort must be greatly strengthened in the South, the Central States, the Pacific Coast States, and parts of the Northern Rocky Mountain Region.

### TIMBER CUTTING

Timber-cutting practice must be improved at least to the extent necessary to stop forest devastation. The requirements for the several forest types are set forth in the section entitled "How to Stop Forest Devastation." In general this will mean the adoption, to some degree, of the selective logging system. In many instances it will not decrease the profits of the operation. While this minimum requirement of forestry practice will not insure acceptable future timber yields, it will in most instances prevent erosion and have a measurable effect in establishing improved conditions of water flow.

### REFORESTATION

Trees must be planted on 11 million acres of forest lands and submarginal agricultural lands where conditions are critical. This will lead not only to improved watershed conditions but to production of needed additional supplies of wood. Most of the lands that should be planted are now in private ownership. The program for planting is fully discussed in the section of this report entitled "Reforestation of Barren and Unproductive Land." Table 9 gives the approximate acreage that should be planted for watershed protection.

TABLE 9.—*Areas proposed for public acquisition, and areas requiring restoration of cover, for watershed protection*

| Drainage | Areas to be acquired | | | Areas requiring restoration of cover | |
|---|---|---|---|---|---|
| | Submarginal agricultural land | Forested land | Total | To be reforested | To be otherwise revegetated |
| | *Thousand acres* | *Thousand acres* | *Thousand acres* | *Thousand acres* | *Thousand acres* |
| Northeastern | 900 | 6,900 | 7,800 | 500 | |
| South Atlantic | 3,300 | 15,500 | 18,800 | 2,000 | |
| East Gulf | 4,600 | 15,400 | 20,000 | 1,000 | |
| West Gulf | 400 | 1,900 | 2,300 | 250 | |
| Lower Mississippi | 1,200 | 4,600 | 5,800 | 250 | |
| Arkansas—Red | 2,200 | 17,000 | 19,200 | 750 | |
| Ohio Valley | 6,000 | 22,600 | 28,600 | 4,000 | |
| Upper Mississippi | 2,500 | 4,600 | 7,100 | 500 | |
| St. Lawrence | 300 | 700 | 1,000 | 500 | |
| Missouri | 400 | 7,200 | 7,600 | 1,000 | 150 |
| California | | 10,000 | 10,000 | 75 | 100 |
| Colorado | | 2,800 | 2,800 | 150 | 200 |
| Rio Grande | | 5,000 | 5,000 | 50 | 50 |
| Great Basin | | 1,800 | 1,800 | 50 | 200 |
| Columbia | | 12,400 | 12,400 | 150 | 200 |
| Pacific Cascade | | 5,000 | 5,000 | 100 | |
| Total | 21,800 | 133,400 | 155,200 | 11,325 | 900 |

### GRAZING MANAGEMENT

Grazing management must be improved, particularly on private lands, and must be introduced on public lands now unmanaged. On forest lands in the East (particularly farm woodlands) and range lands in the West (both private and unmanaged public) where improper grazing use has resulted and is resulting in widespread erosion and increased run-off, management practices must be applied that will not only stop deterioration but permit the vegetative cover to

regain its original density and effectiveness. Artificial revegetation of some 900,000 acres at a cost of perhaps $3,000,000 seems to be desirable. Aside from watershed-protection requirements, such action is obviously essential to permanency of the livestock industry, particularly in the West. This subject is presented in detail in the section of this report entitled "A Forest Range Program."

### SPECIAL MEASURES

On a limited area serious erosion now in progress can be checked only by special measures, frequently of an engineering character. These will include such measures as the installation of flumes at the head of active gullies, the construction of check dams, the scattering of brush, and the building of temporary retaining walls. Detailed estimates of the cost of such measures by regions have not been made, but such data as are available indicate the need for an expenditure of perhaps $20,000,000. In general such measures will be the first step toward the reclothing of the affected areas with a permanent cover of grass, brush, or trees.

### REHABILITATION OF ABANDONED AGRICULTURAL LAND

Fully 70 percent of the erosion problem and 40 percent of the water-flow problem in the East result from improper agriculture. The remedy is (1) to improve agricultural methods so that erosion will be lessened and soil fertility maintained on supermarginal lands, and (2) to rehabilitate through forestry those submarginal lands which contribute to stream-flow and silting problems. Here we are concerned only with the latter. This will involve (1) fire protection to permit natural revegetation or reforestation where possible, (2) forest planting on land where erosion would otherwise continue, and (3) special measures where successful reforestation would otherwise be impossible because of soil movement.

### RESEARCH

Exact experimental evidence upon which to base the management of watershed lands is far too meager, both here and abroad. The varied and complex influences of climate, forest type and condition, and character of soil on stream flow and on erosion must be carefully determined if forest-land management is to meet watershed-protection requirements. A conservative program that would meet this need is presented in the section of this report entitled "Research in the United States Forest Service, a Study in Objectives."

### METHODS OF MEETING MANAGEMENT REQUIREMENTS ON PRIVATE LAND

The benefits to be derived from proper watershed management in large measure accrue to the public rather than to individual landowners. Except where conditions on the land constitute a demonstrable menace, corrective action should be financed, at least in large part, by the public rather than by the private owner. It has been shown that the greatest watershed problems exist on private land and unmanaged public land. Three avenues of approach are open to the private-land problem, each offering a different measure of promise.

### COOPERATION

Public cooperation with private owners on a voluntary basis is the approach that has been followed in this country to date. By public financial aid the owner is encouraged to meet acceptable standards. That this method has failed is clear from the fact that today, after more than 20 years' effort, 46 percent of the private forest land is without organized fire protection and little more than 2 percent is handled in a way that promotes natural reproduction. In some States the private owners are indifferent to the need for fire protection. Private contributions in the West are almost exclusively for protection of virgin timber rather than for maintaining a satisfactory cover on cut-over land.

If satisfactory watershed management is to be had by this method, much, and perhaps most, of the cost of management will have to be borne by the public. Fire protection, except on virgin timberland, will be principally at public expense. Reforestation of large areas of devastated forest and submarginal farm lands will have to be undertaken or heavily subsidized by the public, and special measures, sometimes costly, will have to be taken, with little or no cost to the owner. Such action, without definite assurance that the land will be permanently managed in such a way as to protect the public investment, has little to recommend it.

### REGULATION

Private ownership with public regulation of use is the second possible solution. This approach is common in European countries. The cost would be even heavier than under the cooperative plan. With land abandonment now common, it seems clear that the addition of any expense or of any restrictions on use would simply speed up this trend and result in much needless friction. Like all regulatory measures, this system would depend for its success on public sentiment. Past experiences do not permit optimism with regard to the functioning of unpopular legislation. Regulatory forest laws have been enacted by most of the States, but they do not have adequate public support and have not in general been effectively enforced.

### PUBLIC OWNERSHIP

Public ownership and management of major-influence forest land that can be blocked up for satisfactory administration and of agricultural land highly subject to erosion is the third possibility. Obviously it is unnecessary to propose public ownership of land in these classifications that, because of timber or other values, will be managed reasonably well in private ownership. This method would accomplish by direct action what the alternative methods would attempt to bring about through indirection. Under this method the public would of course pay all the cost of management and protection; it would receive, however, not only the benefit of improved watersheds but the more tangible benefits accruing through sale of forest and range products. In the long run the projects would be self-liquidating.

Public acquisition of major-influence watershed lands appears to be the most logical solution. Present trends indicate that the cost per acre would be low. Federal, State, county, and municipal govern-

ments should proceed with the acquisition of such lands as rapidly as such programs can be financed. Table 9 presents, by major drainage regions, the program that on the basis of present information appears advisable.

## BRINGING UNMANAGED PUBLIC LAND UNDER SUITABLE MANAGEMENT

On public watershed land now unmanaged the public should redeem the obligations of ownership by instituting management of the type recommended in the foregoing. The public domain is the outstanding example of unmanaged Federal lands. The first step in the direction of bringing public-domain watersheds under management would be approval of legislation authorizing the public administration of these lands substantially as recommended in the section of this report entitled, "Public Domain and Other Federal Forest Land."

State and county land now unmanaged should be placed under management as rapidly as possible, although this action will not always be easy. Large aggregate areas are coming into State and county ownership as small tracts of devastated forest or submarginal agricultural land. Comprehensive planning is needed to work out the most feasible division of responsibility and methods of administration. To block the areas up into administrative units would require the purchase of additional lands and exchange of ownership among various public agencies including the Federal Government.